Clinical Consensus Document

Audiological Services for

Musicians and Music Industry Personnel

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Task Force Members
Michael Santucci, AuD, Chair
Marshall Chasin, AuD
Kris Chesky
Brian Fligor, ScD
Melissa Heche, AuD
Colleen Le Prell, PhD
Heather Malyuk, AuD
Cory Portnuff, AuD, PhD
Lisa Tannenbaum
Frank Wartinger, AuD

Select Peer Reviewers
Bob DiSogra, AuD
Laura Sinnott, AuD
Chris Spankovich, AuD, PhD, MPH
Jennifer Tufts, PhD

1. Introduction

This document was prepared by the American Academy of Audiology (Academy) Task Force for the audiological services and prevention of hearing disorders in musicians and music industry personnel. The task force members were selected based upon their clinical and scientific expertise in the prevention of music-induced hearing disorders. The goal of this document is to provide recommendations and strategies for best practices in a comprehensive hearing loss prevention plan for musicians and others that work in the music industry. Evidence based recommendations are drawn from a review of the literature in peer-reviewed and non-peer reviewed journals where possible. In the absence of scientific data, consensus practice was considered in making recommendations. Additional research that would facilitate the further development of evidence-based guidelines is recommended in the document when appropriate. This guideline focuses on hearing loss prevention strategies and hearing protection devices for musicians and music industry professionals. This document does not address music exposures for those who are not involved in the music industry (i.e. concert goers, venue employees, etc.).

1.1 Unmet needs for the hearing health care of music industry professionals

Musicians are at risk for auditory injury from loud musical exposures, which can result in hearing loss, tinnitus, distortion of sound, dysacusis, diplacusis, and hyperacusis. The presence of these Music Induced Hearing Disorders (MIHD) in music industry professionals is well documented. As in other populations, hearing impairment may result in communication difficulties and health related quality of life degradation. In addition, hearing impairment in music industry professionals can be a severe threat to their careers and art, not only reducing the ability to perform and gain personal joy from involvement in music, but also often threatening employment.

Most doctoral programs in audiology offer no formal training in hearing loss prevention strategies for musicians; thus, many new and experienced audiologists lack training and knowledge of sound reinforcement and hearing conservation strategies in musical settings. At the same time there is an increase in the music industry population seeking audiological assistance for ear impressions for music industry products such as high-fidelity earplugs (passive and active) and in-ear monitors. Musicians assume audiologists are educated to be the experts and gate keepers for safe use of these devices. Without proper education and guidelines, audiologists may find themselves providing devices that may be less than optimal or potentially dangerous.

This guideline is not intended to endorse the selection of specific hearing loss prevention-related products but instead provide evidence-based recommendations for how to verify the safe use of in-ear monitors, how to verify appropriate attenuation and frequency response of earplugs, and how to deliver comprehensive hearing loss prevention services and counseling to musicians.

Although this guideline reflects expert consensus, it is a living document that will require updates; technology and treatment options are rapidly evolving in this arena. Therefore, this Task Force will meet from time to time to address new technologies for this population.

2. Music-Induced Hearing Disorders

Excessive exposure to music of sufficient level and duration can cause hearing loss and other auditory system disorders including tinnitus, distortion, hyperacusis, diplacusis, and dysacusis (Zhao et al, 2010). Taken as a whole, these auditory maladies are termed Music-Induced Hearing Disorders (MIHD). They can occur in isolation or in combination in individuals with occupational or recreational exposure to music. The term *music-induced* importantly implicates all genres of music (not just rock music or 'heavy metal" music) as a stimulus that is capable of inflicting injury to the auditory system; thus alleviating the misconception that desired and enjoyable music sounds are less dangerous than unwanted or obtrusive noise sounds.

2.1 Music-Induced Hearing Loss

Similar in clinical presentation to its industrial counterpart, noise-induced hearing loss (NIHL), music-induced hearing loss (MIHL) is characterized by either a temporary or permanent loss of hearing sensitivity secondary to overexposure to music. Temporary threshold shifts (TTS) may occur with prolonged and/or intense exposures; with TTS, symptoms typically resolve within hours to days. Repeated exposure and/or longer, more intense exposures can lead to permanent threshold shifts (PTS) (Ryan et al, 2016).

MIHL differs from NIHL in several ways: (a) music is expressly identified as the damaging stimulus, (b) certain musical settings and sources yield a higher incidence of asymmetric hearing loss, (c) music exposure results in less predictable clinical presentations due to higher variability in exposures. This is attributable to inter-subject differences in work settings, particularities and uniqueness of musical genres, and irregular exposure schedules.

Typically, NIHL presents as bilateral and symmetric in degree. This is mainly due to the omnidirectional nature of most low-frequency dominated industrial noise sources and reverberant occupational settings. In contrast, certain subsets of musicians demonstrate a higher incidence of asymmetric hearing loss attributable to the asymmetric noise exposure from their personal instrument (such as violins, violas, and percussion) or their exposure to other dominant sound sources including other instruments or speakers (Chasin 2010; Schmidt et al, 2011). In addition to relatively close near-field lateralized sound sources, the head shadow effect offers increased protection to the contralateral ear due to increased weighting of mid-to-high frequencies in most music signals relative to industrial noise, and decreased early-reflection reverberation in many music performance settings as compared to industrial settings.

Beyond the many psychosocial impacts of hearing loss affecting communication and daily life, significant decreases in hearing sensitivity can dramatically reduce one's ability to hear his or her own performances as well as others when performing in ensembles. To the musician, this can be unsettling, especially if perceived as a rapid change. Since many music performances are at high sound levels, some stage musicians find mild or even moderate hearing loss to have some type of impact. However, even a slight decrease in hearing sensitivity can pose a challenge to some music professionals' performance, as well as the performance of non-musician professionals with critical listening roles such as mixing engineers, mastering engineers, and audio restorationists.

2.2 Tinnitus

Tinnitus is perhaps the most reported form of MIHD among musicians. Tinnitus can be present in the absence of MIHD (Schmidt et al, 2011; Toppila et al, 2011); however, many patients with tinnitus have concomitant hearing loss and the severity of the tinnitus is often correlated with the amount of lifetime sound exposure (Mazurek et al. 2010; Schmidt et al. 2019). Temporary tinnitus frequently corresponds with TTS and should be interpreted as a warning sign for potential auditory injury. Chronic tinnitus is accompanied by significant comorbidities of anxiety, sleep disorders, and depression (Bhatt et al, 2017). Music professionals often report additional complications from chronic tinnitus including auditory distraction during performances and reduction in music listening enjoyment. Involvement in professional activities can be further limited by concern of increased tinnitus loudness perception and decreased sound tolerance following music exposure.

2.3 Decreased Sound Tolerance

Heightened sensitivity to sound intensity often accompanies hearing loss with or without tinnitus and can be particularly disabling for music professionals. Decreased sound tolerance (DST) can also occur with normal hearing sensitivity (termed hyperacusis) or as a sequela of hearing loss (termed recruitment). Physical pain can be experienced with sound of even moderate intensity, and consequently the individual may develop a fear of sound, or phonophobia. Considering that music professionals' chosen careers are intrinsically anchored in the creation, perception, and enjoyment of sound, the development of phonophobia can represent a significant hardship. Self-treatment of DST is not recommended. Self-treatment often leads to increased sound sensitivity due to maladaptive actions such as improper earplug selection, overuse of hearing protection, and sound avoidance. DST can dramatically limit a musician's participation in professional activities of all intensity levels from solo rehearsal, to controlled production work, to full-volume public performances.

2.4 Diplacusis and Dysacusis

Two additional auditory disorders, diplacusis and dysacusis, can be particularly distressing for musicians. Diplacusis is characterized by a change in pitch perception, often described as perceiving one pitch differently in each ear. Dysacusis is characterized as a decrease in auditory clarity, presenting as distortion of tone frequency or sound quality in one or both ears. The perceived magnitude of the pitch and timbre distortions are correlated with the intensity of the sound stimulus for many individuals. Diplacusis poses a notable handicap to the pitch accuracy of musicians from all genres. For the performing musician, diplacusis or dysacusis may cause a significant enough impairment to threaten a musical career.

Though diplacusis and dysacusis have a lower incidence than a MIHD, it is likely that the incidence in the general noise-exposed population is under-reported due to their relatively subtle perceptual nature, communal fear of admitting such disorders, and their limited inclusion in NIHL research (Laitinen and Poulsen 2008; Di Stadio et al, 2018). Furthermore, the deleterious effects that diplacusis and dysacusis may play on speech understanding, particularly in a noisy environment, may be underestimated. Further study is needed on both the prevalence of other auditory perceptual disorders in the general population and music industry professionals, as well as the auditory effects of these disorders on these two populations.

3.0 Clinical Encounters

Why Musicians seek Audiology services

Musicians and music industry personnel often seek the professional services of an audiologist for various reasons. Some desire audiological expertise regarding MIHD, while others seek audiologists solely for ear impressions for custom products. As the experts in hearing and hearing loss prevention, audiologists are the gatekeepers for hearing wellness and must provide quality hearing services for those in the music industry.

One of the primary motivations for many musicians' first visit to an audiologist is to acquire ear level equipment, or, "ear gear." While ear level equipment is important for hearing conservation in the music industry, this ear gear closes the ear canal and changes acoustic perceptions. Substantial barriers to proper use of hearing protection devices thus exist, and it is the role of the informed audiologist to guide the music industry professional to the best quality of care, sound, and consistency of use possible.

The process of discussing or fitting additional gear must consider that a musician has been auditorily training to the sound quality of an open ear canal his or her entire career. As such, the fitting of gear on musicians should be regarded as a *process* that requires a high level of care and knowledge. This process and the equipment of interest to audiologists caring for musicians' hearing is discussed in detail in section 4 of this consensus document. The focus of this section of the document is best practices during the rest of the clinical encounter. While many of the practices below overlap with conventional best practices, there are important distinctions. The task force members agree that a comprehensive hearing conservation strategy is required for best outcomes for evaluating, treating and protecting a musician's hearing throughout their music career and afterward.

The following elements of a comprehensive hearing loss prevention program are imperative regardless of the reasoning behind a musician's audiologic visit. In other words, it is essential that an audiologist not just take ear impressions and sell products but be providers of care and education to the music industry professional.

3.1 Case History

A case history provides an audiologist with the opportunity to learn about the musician's reason for the appointment, his or her exposure time and sound levels, and any lifestyle or medical markers that may indicate an increased risk of hearing loss or accompanying disorders.

A case history for a musician should be an addition to a traditional clinical case history. Along with typical questions about medical background and risk factors, additional specific questions should include:

1. Reason for visit and background
    a. What is the musician's motivation to see you as a provider?
    b. When was the musician's last hearing evaluation and what were the results?
    c. When was the musician's last loud exposure prior to the visit?
2. Music Exposure:
    a. What genre(s) of music does the musician play?
    b. What instrument(s) does the musician play?
    c. How long is a typical exposure for the musician including rehearsals, performances, recording, and other exposures?
    d. Does the musician know the decibel level to which he or she is exposed?

   e. What are the musician's sources of sound exposure? (i.e., which side of their body has more exposure from monitors on stage or other musicians)

   f. How many years has the musician been playing?

   g. Does the musician perceive his or her environment as being too loud, not loud enough, or comfortably loud?

   h. Does the musician already wear earplugs or in-ear monitors and, if so, what kind?

   i. Does the musician know how loud they are running their in-ear monitors?

3. Symptoms

   a. Does the musician perceive any hearing loss?

   b. Is the musician experiencing any of the following disorders?

      i. Tinnitus

      ii. Hyperacusis/Hypersensitivity

      iii. Dysacusis/Distortion

      iv. Diplacusis/Frequency perception issues

      v. Difficulty hearing and understanding speech in background noise

4. Non-music exposures

   a. Does the musician have any loud hobbies or work requirements outside of his or her musical life? If so, is hearing protection utilized?

3.2 Audiometric Evaluation

The hearing evaluation is a cornerstone of any hearing conservation program. Obtaining a baseline hearing test is necessary both to identify any existing hearing loss and to serve as a reference during follow-up evaluations. Comparison of future tests against the baseline will allow the audiologist to determine if the musician is taking the correct steps and maintaining his or her current hearing status.

A hearing evaluation for musicians is much like a typical evaluation in that pure tone air and bone conduction should be completed, in combination with any clinically necessary tests such as speech testing, immittance testing, otoacoustic emissions, etc. At the minimum, pure tone air and bone conduction thresholds should be tested. In looking for any signs of sound-induced hearing loss, it is recommended that inter-octaves be tested

- 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, and 8 kHz

If the audiologist has the equipment and time to do so, it is recommended that any available frequencies above 8 kHz be tested. The frequency range utilized by musicians and audio engineers is far wider than the typical test frequencies used for communication assessment.

3.3 Consultation / Education

Musicians are bombarded daily with marketing from manufacturing companies that make earplugs and in-ear monitors. As such, an appointment with an audiologist might be the one and only chance the musician must speak with someone who can teach them the science behind sound and corresponding danger or safety. Most musicians crave education about hearing as the ear can be considered an instrument, just like a guitar or violin. The audiologist should take advantage of any time with a musician to provide education about the anatomy and physiology of the auditory system, as well as risk factors of MIHD. After completing the hearing evaluation, teaching the musician about the audiogram and how it is used to track hearing (i.e., keeping an eye on “noise notch” frequencies) facilitates self-advocacy and confidence in the benefits of returning for annual evaluations.

It cannot be stated enough that education and motivation are paramount in clinical care of musicians.

3.4 Ear Impressions

Ear impressions are a primary reason musicians will seek out audiologists. Custom devices such as earplugs and in-ear monitors are often a status symbol within the music industry, serving as a sign that someone has "made it." However, the way the ear impressions are taken can dictate aspects of said custom devices such as frequency response, sound quality, and sound isolation.

The skill of taking good ear impressions will be facilitated by:

- The use of a very high viscosity silicone
    - A high viscosity ear impression material will distend the ear canal slightly to allow a tighter, more accurate seal in the ear canal
- Taking the ear impressions beyond the second bend of the ear canal and with a full helix
    - This allows for optimal isolation of in-ear monitors, as well as a clear impression of the anatomy needed by manufacturers to create precise sound bore characteristics to meet specifications on earplugs and in-ear monitors
    - A full, well-filled helix offers a precise anatomic impression needed by manufacturers of in-ear monitors, which are full shell devices
- For soft material products such as earplugs and silicone in-ear monitors, having the patient mimic what he or she will be doing while wearing the devices as the impression material sets (e.g., singing, playing an instrument, moving the head/neck/jaw)
- For acrylic in-ear monitors, having the patient mimic typical movements (as described above) or following recommendations from the manufacturer are both acceptable strategies

3.5 Fitting, Verification, and Orientation

When a custom device is ordered, fitting and fit verification is strongly recommended. This fitting appointment facilitates proper insertion, removal, and cleaning by the musician. In addition, it allows the audiologist to adhere to best practices on verifying device attenuation using real ear testing procedures (see section on gear for verification methods). This appointment also allows the audiologist to provide new education to reinforce any previous information about use of the devices. The musician should be encouraged to return for an annual hearing test and re-verification of devices.

3.6 Follow-up Serial Evaluation and Support

There is an ethical responsibility that care for music industry patients must go beyond just the taking of ear impressions and fitting hearing protection or ear monitors. Creating a firm rapport at the initial appointment should lead to an ongoing relationship of support and, ideally, annual hearing evaluation visits. Since hearing conservation with most musicians is voluntary, serial audiograms are not required to be performed annually. It is possible that a musician might only return to an audiology office when he or she needs a new product, but that does not mean that the initial visit should not have a high standard of care. Therefore, audiologists can look at the initial encounter with a musician as a chance to be ambassadors of healthy hearing and not solely impression takers.

4.0 Gear for the Music Industry

As introduced above, the ear level equipment that is important for hearing conservation closes the ear canal and changes acoustic perceptions. Given that a significant portion of the music industry is not legally required to wear hearing protection, despite being exposed to hazardous levels of sound (Westmore and Eversden 1981; Chasin and Chong 1991; Miller et al, 2007; Opperman et al, 2006; Maia and Russo 2008; McIlvaine et al, 2012), use of protective devices is completely voluntary for that portion of the industry.

Education, self-efficacy, and motivation to use protective ear gear consistently and correctly is urgent and critical to the success of hearing conservation efforts. This section of the best practices document is designed to walk the practicing audiologist through considerations while choosing and fitting products designed for musical use, such as filtered earplugs and in-ear monitors, to music industry professionals. It is intended to be an overview of available types of gear and, as such, will not mention companies, clinics, or manufacturers by name.

4.1 Earplugs

For musicians, earplugs are often the first line of defense in preventing MIHD. Earplugs come in varying shapes, sizes, and styles, and can be categorized into two overarching groups: universal or “one-size-fits-all” fit and custom fitted products. Those categories can be further divided into passive and active attenuation. For musicians, however, the considered characteristics are often sound quality, comfort, and cost. The role of the audiologist is to know (1) the correct way to choose the recommended level of attenuation for a musician; (2) how to fit a musician for optimal sound quality; (3) how to verify said fit; and (4) how to educate and counsel accordingly.

In the music industry, performance is key and, without a perfect fit, accompanied by great care and counseling from a knowledgeable audiologist, hearing protection will likely not be properly and effectively utilized by the music industry professional.

4.2 Passive Earplugs

4.2.1 Selection Criteria

Choosing a style and manufacturer of passive earplugs will be dependent on many factors that should be discussed during case history. Length of sound exposure, professional setting, instrument type, and personal preferences must be considered by the audiologist. Perhaps the most important factor in choosing earplug style is frequency response, which should be uniform attenuation across as much of the audible frequency spectrum as possible in order to give the musician his or her best chance to ear train to hearing protection. Care should be taken to not over-attenuate the musician beyond the minimally necessary attenuation level. Additionally, giving greater attention to counseling on ear training to and appropriate expectations of earplugs can be essential.

While the audiologist may be tempted to base recommendations of earplug attenuation on instrument type or musical genre, the most appropriate way to choose attenuation is to calculate exposure (dose) based on sound level and duration. As music does not have a dedicated safety scale, the current method for choosing amount of attenuation for a musician is essentially the same as for industrial workers exposed to occupational noise.

In the United States, the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) scales are used for calculating exposure and risk of hearing loss (NIOSH, 1998; OSHA, 1983). OSHA has a permissible exposure limit of 90 dB (A) for eight hours, with safe durations for sounds at other levels calculated using a 5-dB exchange rate (meaning the exposure length must be cut in half with each increase of 5 dB (A)). NIOSH has a recommended exposure limit of 85 dB (A) for eight hours, with safe durations for sounds at other levels calculated using a 3-dB exchange rate. When sound exposure exceeds these limits, it is considered hazardous and the duration of exposure must be decreased, the sound level must be decreased at its source, or the worker must wear hearing protection to decrease their individual exposure. Compliance with OSHA limits protects approximately 75 percent of the population while compliance with NIOSH limits protects approximately 92 percent of the population.

It is difficult to know the exact intensity of music to which a given musician is exposed, especially when seeing the patient only in the clinic. Sound level measurements at venues, rehearsal spaces, and on stage should be taken if possible. If there is no opportunity to complete a sound level measurement, attenuation needs can be based on exposure duration and *estimated* sound pressure level. Caveats to this method are individuals who are more prone to the occlusion effect, such as wind players and vocalists, and those who are experiencing MIHD.

4.2.2 Universal Fit Earplugs

There are a wide variety of over-the-counter, universal fit earplugs available to music industry professionals. There is significant variability in frequency response across universal fit hearing protection marketed by different manufacturers (Zaccardi et al, 2018; Zaccardi and Le Prell 2019). If a music industry professional opts for an OTC product, counseling is imperative and should emphasize these differences. There is also variability in individual ear canal fit. As such, there is additional variability in achieved attenuation beyond differences that are expected due to the diverse Noise Reduction Rating (NRR) values across products. A portion of the variability in attenuation is related to improper fit due to improper insertion of HPDs by the user. For audiologists who recommend universal fit earplugs, knowledge of frequency response, actual attenuation versus NRR, and instruction on proper insertion are essential (Tufts et al, 2013).

4.2.3 Custom-Fit Earplugs

Custom, filtered earplugs can offer the professional musician a flatter, more reliable frequency response and more consistent attenuation. Anecdotally, the desire or need for custom earplugs are what first lead many musicians and others in the music industry to audiologists. The frequency response of an earplug is specifically provided via a specially designed acoustic diaphragm or filter (Killion et al, 1988). There are several filters available from which an audiologist may choose, and a well-informed audiologist will compare frequency responses of available models and choose the flattest possible response. Frequency response of the filters offered by different manufacturers can be measured in the clinic using free field or probe microphone measurements (Portnuff and Price 2019).

When choosing a manufacturer for custom, filtered earplugs, the audiologist must take into account the material used (silicone, vinyl, etc.) and whether or not specifications of make are met for filter frequency response. Importantly, the manufacturer of the HPD and the manufacturer of the filter can be different companies, and the filter manufacturer cannot guarantee a final, flat, in-ear frequency response when the filter is used across the variety of custom HPDs. Frequency response characteristics can vary between custom earplug manufacturers, depending on the manufacturer's attention to the production parameters of the earplug. While it is outside the audiologist's specific role, audiologists should be aware that each custom earplug manufacturer should verify that the finished product meets specifications. Manufacturers of custom earplugs use a variety of materials including vinyl blends and silicone. Medical-grade silicone earplugs have more longevity than vinyl as they do not shrink over time.

For hearing conservation, maintenance of seal is imperative and medical-grade silicone provides the user the best chance of earplug longevity. Of equal importance is the skill and technique of the audiologist's ear impressions (See Section **3.4 Ear Impressions**). For example, during the time in which the ear impression is setting, a wind or brass player should use his or her embouchure to consider any displacement or torqueing of the ear canals. Equally as important as movements, and perhaps arguably more important for proper fit, is the use of high viscosity impression material. Using such material will increase the rate of proper isolation and fit as it distends the ear canal (Lerner, 2015).

4.2.4 Earplug Verification—Rationale and Procedure

When possible, a fitting appointment should be conducted to ensure proper insertion and that the product meets the manufacturer's specification. Several methods of verification exist.

A recommended fit test for measuring attenuation of passive hearing protection is the real-ear attenuation at threshold (REAT) measurement. REAT verification involves measuring hearing sensitivity thresholds with and without earplugs in place. At a minimum, 0.25 and 4 kHz should be measured, the lower frequency being used to verify fit and presence or absence of slit leaks, and the higher frequency being used to verify specifications of the filter (Portnuff and Price 2019). If possible, the audiologist should use a step size smaller than 5dBHL to achieve a more exact REAT measurement. The REAT test is easily measured in a clinical environment via circumaural headphones or sound field. If sound field is used, head position should remain constant and warble tones or narrowband noise should be used. An alternative measurement to REAT is taking a probe microphone measurement in the ear canal of earplug attenuation. However, probe microphone measurements are best achieved when using a specially designed filter probe system to avoid slit leak. In the presence of a slit leak, attenuation of energy at low frequencies is significantly compromised.

4.3 Active Attenuation

Active attenuation refers to HPDs, which use a dedicated power source and circuitry. Active earplugs can be universal fit or custom, but as with passive earplugs, a custom fit offers greater reliability in attenuation and sound quality.

Active attenuation can offer musicians more flexible attenuation (O'Brien et al, 2014) and the ability to communicate more clearly when sound intensity levels are not hazardous. While some active attenuation products accomplish this with automatic digital signal processing, other products are analog and allow the user to increase attenuation via manual controls. As with passive hearing protection, the best quality of sound will come from a frequency response that is as flat as possible. It should be noted that active hearing protection, particularly automatic styles, can have hardware limitations such as limited headroom. For inputs such as dynamic music, circuits with limited headroom can clip and even shut down with high intensity inputs. Verification of active hearing protection should be completed with a probe microphone system and inputs appropriate to measure the attenuation levels.

4.4 In-Ear Monitors

In-ear monitors (IEMs) are custom earphones worn by music industry professionals to hear a particular and exact mix of musical sounds and are often used to replace stage monitors (also known as “wedges”). Sound pressure levels on a professional musical stage can easily become hazardous to hearing due to the complexity of the auditory environment and extreme signal-to-noise ratio needs. A music venue with live performers must balance the output from the PA system pointed at the audience (controlled by a front of house engineer) along with the monitoring needed by the performers to clearly hear their individual mixes of sound on stage, provided by a monitor engineer or the band themselves. As sound levels increase in the audience due to attendance, the acoustics of the venue, the rowdiness of the crowd, and needs of the musicians, so must the sound levels of the wedges. Additionally, as one performer's wedge increases in volume, so must the surrounding wedges. This is known as competitive monitoring, though audiologists may be more familiar with the term signal-to-noise ratio. As each performer strives to clearly hear his or her mix, he or she must increase the wanted "signal" over the unwanted "noise" or competing sounds. IEMs provide the professional musician with many benefits such as a cleaner, high-fidelity signal, consistency in sound from venue to venue, and the potential to reduce sound levels, just to name a few.

IEMs are available in both universal fit and custom versions. While universal fit IEMs are widely used, a music industry professional will typically see an audiologist when a custom product is needed. Custom IEMs come in a variety of styles, both fully isolating and ambient, which vary depending on the material used in manufacturing and number of drivers (speakers) used. For the wearer to have the opportunity to control volume levels and protect hearing, two factors must be maximized: isolation and education.

4.4.1 Ear-Impression Techniques for IEMs

The greatest isolation of IEMs is achieved with a deep, tight fitting earmold. Such depth of fit is achieved through specialized ear impression techniques and material used in the manufacturing of the IEM. As with custom hearing protection devices, ear impressions taken for IEMs should be completed with a high viscosity material and taken beyond the second bend of the ear canal. The high viscosity material will serve to expand the ear canal slightly as it hardens, allowing for a tighter fit. As the material is setting, the audiologist can also maximize fit by having the musician mimic the movements he or she will make while wearing the IEMs or playing his or her instrument if a mouthpiece is used. IEMs are made from either hard acrylic material (similar to in-the-ear hearing aids) or soft silicone. Soft, medical grade silicone will provide the highest isolation due to the ability to be inserted more deeply into the ear canal without pain.

4.4.2 Working with a "Trained Ear" Professional

Experienced music industry professionals have very finely tuned auditory systems which provide them with strong auditory memory. As a result, first time users of IEMs, without proper education, will turn the volume of the IEMs to almost the exact sound level of their previous wedges—regardless of isolation level.

It is the role of the audiologist to instruct the music industry professional on ear training to lower volume levels over time. This can be done by maximizing the benefits of binaural summation. Many musicians must be trained to wear binaural sound-isolating IEMs because they can find binaural occlusion, resulting in maximum isolation, to be disconcerting and "unnatural" during performance. When one IEM is removed, however, binaural summation is lost. Because of the loss of this phenomenon, an increase in volume is needed not only to increase the signal above the "noise floor" to which the musician is now exposed, but also to account for central masking in the auditory system. For individuals who can ear train to isolating IEMs at an appropriate volume, studies have shown a decrease of 6-12 dB SPL in volume (Federman and Ricketts, 2008).

4.4.3 Ambient Sound Monitoring

For musicians who feel they cannot perform with two isolating earpieces, or for musicians who crave a more "natural" approach to monitoring, ambient IEMs are available. Musicians wanting ambient sound added to their mix can consult with their monitor engineer regarding the placement of ambient mics around the stage. These microphones allow crowd and acoustic sounds to be mixed into the monitor signal and can give the performer a limited sense of spatial awareness. However, pinna effects and head-related transfer function are still absent in this condition, often leaving the performer wanting a more natural, ear level sound.

Ambient IEMs come in two styles: passive and active. Like earplugs, passive simply means there is no active circuitry or power source involved and no reproduction of sound is taking place.

Passive ambient IEMs can either have a sound bore drilled into the earpiece and left open, or a filter can be placed into said bore. For the prevention of hearing loss and MIHD, an open bore should be avoided as it exposes musicians to surrounding sound levels and will ultimately require an increase in listening volume. Passive IEMs with a filter in place can offer the musician access to surrounding sounds but will still be limited by the frequency response of the filter. A musician's best chance at a more natural experience with IEMs is to use an active ambient IEM.

These IEMs are designed with miniature microphones in the earpieces that will reproduce ambient sounds in real-time to be added into the performers mix. The microphones can be controlled in discrete increments to allow the performer to choose as much or as little ambient sound as he or she prefers. Counseling regarding reduction of ambient levels to achieve reduction of mix levels is essential in this condition. Much like active earplugs, active ambient IEMs can have limitations regarding hardware. The audiologist must note the aspects of microphone technology such as frequency response and headroom before recommending these systems to a musician. Though several active ambient options exist, not all are created equally, and hardware limitations will vary between manufacturers.

4.4.2 In-Ear Monitor Device Options

When choosing IEMs, the number of drivers (speakers) must be taken into consideration. With each added driver, sensitivity of the earphone is doubled. This can lead the performer to lack control over sound levels. Manufacturers incorporate additional drivers for a myriad of reasons such as creating a more robust bass frequency response (for example, if lack of an isolating seal is possible), creating a more detailed signal, or simply for marketing reasons. With proper seal and education, it can be argued that no more than one driver is needed per earpiece.

For a music industry professional to use IEMs on stage, he or she will need to be connected to a device from which a mix will be received. For musicians who do not require mobility on stage, a hard-wired system can be used. For musicians who need more mobility, wireless receivers and transmitters are required. These systems consist of a transmitter that is plugged into the mixing console of the monitor engineer as well as a belt pack the performer wears in order to receive the mix.

4.4.3 In-Ear Monitor Best Practices

Verification of IEMs can be completed via in-situ probe microphone measurements. This can be a near impossible task for an audiologist to complete on a musician who is on tour. Verification measures exist that plug in-line into the signal chain created by the belt pack to the IEMs. Such a system measures the drive voltage from the belt pack to show the user how loud he or she is listening using both dB SPL and NIOSH or OSHA safety scales.

While this best practice guideline introduces a variety of technical issues the audiologist must recognize and understand that, it is not possible for a single best practices document to educate the audiologist on the practical implementation of clinical decision-making on IEMs. Additional continuing education and experience is necessary to become competent in the selection and safe use of these products. IEM manufacturing is a competitive field with new devices being promoted regularly. It is up to the ethical audiologist to critically read, on an ongoing basis, the current white paper research on devices released and to deduce whether or not the science is reliable. An IEM manufacturer can claim anything it would like regarding lessening of fatigue on the auditory system or reduction in sound pressure level without a reduction in volume on a belt pack. However, the audiologist will be considered the most reliable gatekeeper to help him or her preserve hearing and prevent music induced hearing disorders.

4.5 Additional Considerations

Any appointment with musicians should include questions regarding use of hearing protection in other loud or noisy areas of a musician's daily life (see Section **3.1 Case History**). If the music industry personnel are exposed to additional sources of hazardous sound levels, appropriate hearing protection should be properly fit and discussed. Beyond the need for hearing protection from non-musical sources of sound (such as motorcycles, gunfire, farming, woodworking, etc.), audiologists should also counsel music industry professionals on the risks of listening to music, whether at live concerts or via personal music players. Musicians listen and they often listen for hours at a time. Well-fitted, custom earphones to use while traveling on busses, vans, and airplanes can be ear-savers for touring musicians. For non-traveling musicians, they are just as valuable for safe listening throughout the day.

5.0 Gaps in Knowledge

5.1 Sound Measurement

There are many unknowns regarding professional musicians and their risks for hearing loss and MIHD. One important unknown is the extent to which the damage risk criteria established for occupational noise limits are appropriate to apply to music. There is a higher incidence of hearing loss potentially impacting speech understanding and communication when more sound exposure is allowed, and there is no reason to think that these broad relationships will not also be true within musicians and other performing artists. When counseling musicians and other performing artists on safe listening behaviors, as with counseling workers exposed to occupational noise, a critical first decision are the sound levels that you identify as "safe" for the individual performer (OSHA PEL, NIOSH REL, see Section **4.2.1 Selection Criteria**).

5.1 Are the Risks of NIHL and MIHL Equivalent?

Music exposure is systematically different from occupational noise exposure in several important ways. Not only are spectral content (frequencies at which sound is produced) and dynamic amplitude variation (distribution of peaks and valleys) different for music and occupational noise, patterns of exposure to loud sound are also different. Musicians and other performing artists have patterns of exposure that often do not follow the 8 hour/day, 5 day/week, 40-year career, exposures expected for workers exposed to occupational noise. For some professional musicians, exposure patterns will include practice and/or performance for smaller numbers of hours per day but sound levels may be higher than many occupational exposures depending on whether the music is amplified and whether the performer is rehearsing alone or with a larger group.

A major unknown with respect to whether unwanted noise and music performance have equivalent risk for the listener/performer is that there are differences in the emotional response to these sounds, which also appears to mediate risk. Whereas few industrial workers wish to experience high noise levels in the workplace, musicians create sound as a performing art, and performance attendees seek (and pay) to experience this sound creation. There are several reports that temporary threshold shift (TTS) is smaller when music is used as an exposure stimulus, compared to exposure to noise, even when the total energy is equivalent (Lindgren and Axelsson 1983; Strasser et al, 2003). Moreover, there is an interesting report in which the effects of noise exposure differed when the noise was delivered in the context of reward versus as a punishment, which is sometimes referred in the literature as "glial excito-toxicity" (Hörmann et al, 1970; as cited in Chasin, 2010). New research efforts to understand the potential for differences in relative hazard across sound exposures (noise vs. music) are needed.

It should be noted that the selection of safe practice/performance exposure criteria is that music-induced tinnitus and other MIHD may have completely different damage-risk relationships and adoption of limits that reduce the likelihood of permanent NIHL may or may not prevent the development of these other disorders, which can be career-limiting. Taken together, new research that establishes auditory risks of music over-exposure are urgently needed not only for music induced hearing loss (MIHL) but also for tinnitus, hyperacusis, and other perceptual disorders.

5.2 Hearing Protection Device (HPD) Recommendations

It is noteworthy that some music training programs have implemented the Performing Arts Medical Association (PAMA)/National Association of Schools of Music (NASM) guidelines for education on NIHL which may prompt some at-risk performers to seek monitoring prior to the development of deficits, although others may not be proactive. Early identification of at-risk individuals, and early intervention in those with progressing hearing loss, provide opportunities for both education and interventions using engineering or administrative controls or HPDs.

As discussed in section 4, above, several “high-fidelity” HPDs, designed to have a flatter attenuation profile across frequencies, are commercially available. In addition to having a flatter attenuation profile, these products also tend to have smaller noise reduction rating (NRR) values, often on the order of 5-15 dB, in contrast to foam earplugs used in industrial settings, which can have NRR values that are closer to 30 dB. Research investigating the opinions of music consumer regarding these products has begun to emerge (Bockstael et al, 2015), and there is also some data from musicians (Huttunen et al, 2011; Santoni and Fiorini 2010; Beach and O'Brien, 2017) and music student (Chesky et al, 2009) populations. Data are also beginning to emerge for active musician hearing protection products (O'Brien et al, 2014). While these data generally are encouraging in showing that high-fidelity hearing protection products are preferred over conventional HPDs, adoption has nonetheless been low in the studies to date. Studies that identify education and training programs that increase acceptance and use of HPDs are needed. In addition, important questions about “how flat is flat enough” need to be answered to understand relationships between high-fidelity sound attenuation products and sound quality ratings using these devices.

5.3 In-Ear Monitors

IEMs isolate the performing artist from environmental sound, which creates an opportunity for them to be used as hearing protection devices, but they are only effective as hearing loss prevention tools when levels delivered via the IEM drivers are set at safe levels. We do not know the prevalence of safe use versus risky use. However, data from Federman and Ricketts (2008) clearly illustrate that in the absence of training and practice, musicians are likely to simply set in-ear devices to the levels they are accustomed to from previous use of floor monitors. There does not appear to be any systematic research in this area since this important initial finding was published. New research investigating both the most effective, and the most efficient, training and monitoring strategies to assure that in-ear devices are set at safe listening levels is needed. This type of research is urgently needed to define evidence-based strategies for preventing hearing loss in performing artists.

5.4 Individual Differences in Susceptibility

Changes in hearing as a function of noise exposure are highly variable within both animal models (Wang et al, 2002) and human participants (Le Prell et al, 2012; Spankovich et al, 2014). One of the factors that might be expected to contribute to individual variability is the resonance of the ear canal, which varies across listeners. It is well known that sound is amplified in the ear canal, and the amount of amplification at each frequency is highly individualized, with total amplification typically ranging from a few dB to as much as 30 dB (Henoch and Chesky, 1999. Potentially relevant acoustic features include both the frequency at which the maximum gain occurs (Rodriguez and Gerhardt, 1991) and the total gain across frequencies (Shotland, 1996). However, there have been few efforts to identify differences in vulnerability as a function of the in-ear amplification and systematic efforts are needed (for recent discussion see Grinn, 2019).

Other individual differences that have been identified as potentially contributing to risk of hearing loss (either in the general population or in workers exposed to noise) include genetics (Sliwinska-Kowalska and Pawelczyk, 2013), cardiovascular health (Agrawal et al, 2008, 2009), and dietary quality (Curhan et al, 2015; Spankovich et al, 2011; Spankovich and Le Prell 2013, 2014; Gopinath et al, 2011). Acoustic reflex strength may contribute to individual differences in vulnerability as a more robust middle ear reflex more effectively reduces the transmission of sound to the inner ear (Karlovich et al, 1977; Borg et al, 1983; Borg et al, 1995).

Efferent reflex strength has also been suggested for potential inclusion in hearing conservation programs as the cochlear response to sound is reduced during activation of the medial olivocochlear system (Marshall et al, 2014), but the data exploring relationships between efferent reflex strength and NIHL in humans have not shown strong relationships (Blioskas et al, 2018; Hannah et al, 2014; Muller et al, 2010).

Few of these factors have been studied specifically within musician populations and we do not know the extent to which genetics, cardiovascular health, diet, efferent reflex strength, middle ear reflexes, or ear canal resonance are associated with the various MIHD commonly reported in musicians and other performing artists.

5.5 "Hidden" Auditory Injury

One of the current topics in auditory science that has gained significant interest among hearing researchers is the recently described phenomena of lasting cochlear synaptopathy after sound exposures that result in TTS, with permanent synaptic pathology remaining despite the recovery of threshold sensitivity (for reviews, see Kujawa and Liberman, 2015; Liberman and Kujawa, 2017). This synapse loss was initially shown to result in decreased auditory brainstem response wave I amplitude in rodent models, and the phenomena was termed hidden hearing loss based on the assumption that an auditory deficit accompanied the decrease in wave I amplitude (Schaette and McAlpine, 2011). Since then, there has been significant interest in other metrics such as ratios of wave V and wave I amplitudes, ratios of the summating potential and action potential amplitudes, and other metrics such as the frequency following response, envelope following response, and acoustic reflex strength (for review see Le Prell, 2019). There is growing consensus within the auditory community regarding best practices for research investigating this phenomenon (Bramhall et al, 2019).

One population in which this disorder has been speculated to occur is music students, based on differences in extended high-frequency hearing, decreased word identification on a difficult word in noise task, and changes in summating potential amplitude (a pre-neural measure of hair cell function) which also drove changes in the ratio of summating potential amplitude relative to the action potential (a measurement of the neural output from the cochlea) (Liberman et al, 2016). Other investigations using populations with various loud music exposure histories did not reveal deficits when populations exposed to loud music were compared to controls (Smith et al, 2019; Samelli et al, 2012; Grose et al, 2017), but it is possible that differences between populations would exist if other metrics that have emerged as potentially sensitive diagnostic tools for cochlear synaptopathy had been included in the test battery. Additional data are needed to understand risk of damage to both music consumers and performing artists; such studies must include tinnitus and hyperacusis symptom surveys, to more fully characterize auditory symptoms not captured by the audiogram.

5.6 Speech-in-Noise Deficits

One of the deficits commonly hypothesized to accompany synapse loss is speech-in-noise deficits. In contrast to harmful effects of noise on various hearing-in-noise tests, Coffey et al, (2017) suggest the preponderance of evidence points to benefits of music training, resulting in speech-in-noise advantages. Adding additional complexity to research questions regarding potential cochlear injury in musicians, and functional correlates of those potential injuries, are the findings from Krause and colleagues, which consistently shows a wealth of brain health benefits associated with musical training, including improved integrity of cochlear neural output (Kraus et al, 2014; Slater et al, 2015; Slater and Kraus, 2016; Strait et al, 2015; Tierney et al, 2013; Tierney et al, 2015). A final area that must therefore be considered is the potential positive effects of musical training on the brain as well as the exposures at which risks begin to outweigh benefits.

Conclusion

In working with musicians and other performing artists, there is no annual audiometric testing requirement for many musicians, other than the subset of professional musicians with a union that lobbies their employer for health protection.

Strategies to access, educate, and motivate health protective behaviors are needed. Little is known regarding the best techniques to motivate hearing health protective behaviors in musicians and more research is urgently needed.

Guidance to musicians at this time is based on occupational noise damage-risk criteria. The hazards associated with music may differ from that of occupational noise, but there are not adequate data to allow different guidance on hearing protection behaviors at this time. Additional research to understand the risks for MIHL and MIHD are urgently needed. A systematic review of the literature would be a worthwhile undertaking.

High-fidelity HPDs are readily available, but there continues to be little understanding of the ways in which attenuation interacts with acceptability. Data addressing the amount of attenuation that is acceptable, and the flatness of attenuation that must be achieved in the listener's ear canal to obtain good sound quality ratings, are not available.

In-ear monitors are often mistakenly assumed to be hearing protection devices, as they occlude the ear canal. They only serve as HPDs if the sound levels produced inside the ear canal are sufficiently reduced relative to high ambient levels. Training to accept reduced levels is likely to be required, but there is little published evidence to guide training strategy. Data documenting current patterns of exposure during in-ear monitor use are needed, in addition to the necessary training and long-term outcome data.

Musicians and other performing artists rely on their hearing for their livelihood. Hearing loss and other auditory disorders can compromise their performance skills. Audiologists working with performing artists must strive to provide best practices, including verification of HPDs and careful education and counseling on in-ear monitors if used. There are multiple areas in which new research data are urgently needed to improve hearing health care for this at-risk population. Updated guidance should be sought as new data emerge.

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