Protecting The Professional Ear: Conservation Strategies And Devices

By James W. Hall III and Michael Santucci

It is well known that exposure to high-intensity levels of sound may cause irreversible damage to the inner ear and result in permanent hearing impairment.[1,2] Exposure to diverse sources of excessive sound energy, such as machinery, heavy equipment, power tools, engines, gunfire, and fireworks, can occur in a variety of settings, ranging from the industrial workplace to the military, from the home to recreational settings.

Musicians and other music industry personnel are regularly exposed to potentially damaging sound levels. The risk to hearing posed by loud music crosses genres, from rock and roll, to country, to classical music. In contrast to the factory worker, the tradesman, or the hunter, the professional musician is extremely reliant on hearing integrity for his or her livelihood. Yet, historically, hearing conservation efforts have rarely been implemented, or even considered, in the music industry.

Recently, we have noticed increased interest in hearing and hearing protection among performers and technical personnel in the music industry. We have also witnessed the development of two new strategies for controlling the intensity level of music without reducing its quality, as well as one very sensitive technique for early detection of sound-related auditory dysfunction.

SOUND EXPOSURE IN THE MUSIC INDUSTRY

Protecting the professional ear might appear rather straightforward in comparison to industrial hearing conservation. Music industry personnel understand the technical and artistic components of sound and music. Terms, such as decibels, frequency response, sound-level meter, distortion, attenuation, and amplification are in their everyday vocabulary. Also, performers and technical personnel have a high appreciation for hearing. Although their understanding of the auditory system and the pathophysiology of overexposure to sound may be minimal, musicians can invariably describe the symptoms quite graphically.

But, in reality, protecting the professional ear is extremely challenging for at least a dozen reasons.

- First, musicians are exposed to high-intensity sounds in a variety of settings and venues, ranging from a studio, to a small club, to a large auditorium. Therefore hearing conservation for the musician must be implemented in multiple sites.
- Second, a musician may perform types of music that differ dramatically in intensity. When sound levels are moderate, little or no attenuation is required; yet, moments later, considerable attenuation may be indicated.
- Even when performers understand and desire the benefits of limiting the intensity of their music, other factors, such as the expectations and demands of the audience, may prevail.
- Musicians may be exposed to high levels of sound for extended periods of time each day both as participants in recording sessions, rehearsals, and performances, and also as listeners to other performers.
- The risk of music-induced hearing loss may differ dramatically among subtypes of performers, in part because of their usual location on stage. For example, a drummer's left ear is at greater risk because the snare drum and high hat are on the left side. The left ear of violinists (or fiddlers) is also at greater risk because of where they hold their instrument. Symphony musicians may be chronically exposed to high sound levels on either the right or left side depending on their location relative to certain instruments (e.g., the percussion or brass sections).
- Vocalists may prefer not to wear ear protection because they fear they will be unable to monitor their voice.
- Most musicians have the equipment to do frequency-specific amplification. Thus, a sound engineer may try to compensate for a high-frequency hearing loss by increasing the output of earphones or stage monitors in the region of the loss.
- There are no established "damage risk criteria" for music exposure, as there are for industrial noise exposure (U.S. Occupational Safety and Health Administration standards).
- Ear protection may not fit the image of some musicians.
- Many musicians who are well aware of their hearing loss may avoid audiologic assessment out of denial or to avoid the risk that their hearing loss—a professional handicap—become known.
- Even if musicians *do* seek help from a hearing care professional, their hearing loss may go undetected if they are given only a simple hearing screening.

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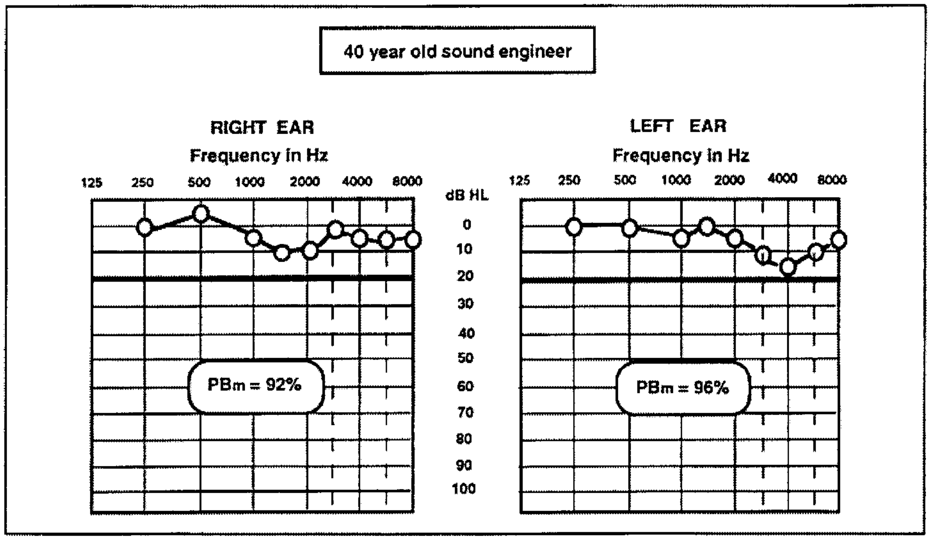

Figure 1. Audiogram for a 37-year-old sound engineer with no auditory complaints (Case 1).

• Finally, busy musicians with hectic recording and tour schedules may not take the time for hearing assessment or ear protection.

EDUCATION COMES FIRST

The first step toward protecting the professional ear is education. Professional musicians must appreciate the possibility that they have been exposed to hazardous levels of sound. One simple way to determine whether or not a musician patient is being exposed to excessive sound is to ask a series of questions.

- Do you need to shout to be heard by others during studio work or performances?
- Have you ever noticed a ringing noise in your ears for hours or even a day after sound exposure?
- Does music sound slightly distorted toward the end of a busy day?
- Do voices sound muffled after you've been around music for an extended time?
- Do your ears sometimes feel full or stopped up?

If the answer to any of these questions is yes, the patient is at risk for noise/music-related auditory dysfunction (inner ear damage) and should undergo a complete hearing evaluation. In addition, a hearing conservation program should be recommended.

HEARING ASSESSMENT

The baseline audiologic assessment includes a thorough otologic and professional history to establish the risk or presence of music-induced and unrelated auditory dysfunction. Next, a conventional pure-tone audiogram, including interoctave frequencies in the region of 2000 Hz to 8000 Hz, is an essential component in the hearing assessment of a professional musician. The conventional audiogram should be supplemented with an assessment of higher frequencies up to at least 16,000 Hz. This requires an oscillator and nonaudiometric earphones, in addition to an audiometer. The high frequencies of the audiogram are actually nearer the mid-frequency region of the spectrum of music heard by the professional ear.

Otoacoustic emissions (OAE) are the most recent and the most sensitive measure of auditory function. OAE are uniquely specific to the outer hair cell damage that results from overexposure to sounds. We have observed that OAE may provide the first indication of cochlear dysfunction, even before the pure-tone audiogram shows any significant decrease in auditory sensitivity.

CASE REPORTS

We will now present three brief case reports to illustrate the value of coupling OAE with pure-tone hearing thresholds in the audiologic assessment of the professional ear.

Case 1: A Sound Engineer

A 37-year-old sound engineer was scheduled for a comprehensive vestibular workup for diagnosis of a balance disorder. He reported a history of more than 15 years of exposure to music, but claimed to consistently regulate the intensity levels of music. He denied any auditory complaints. Hearing sensitivity was within normal limits, with only a very slight notching configuration in the 4000-Hz region on the left ear (see Figure 1 on p. 38). Middle ear function was normal by immittance measurements. An otologic examination showed no evidence of middle ear disease. Word-recognition scores were excellent (92% to 96%) bilaterally. Distortion-product OAE were within normal limits bilaterally at stimulus intensity levels of 65 dB SPL ($L_1 = L_2$) for geometric mean frequencies (for f_1 and f_2) of 500 Hz through 5000 Hz, as recorded with two commercially available instruments (Figures 2a and 2b).

Case 2: A Professional Drummer

A 31-year-old drummer for a nationally known southern rock/country band scheduled an appointment for audiologic assessment and Etymotic Research musician (ER-15) earplugs the day after performing in a concert at an outdoor amphitheater. He reported mild tinnitus, but no apparent hearing loss on the day of the testing. He has been a drummer for over 15 years.

Otologic inspection revealed impacted cerumen bilaterally, so the tympanic membrane could not be visualized. Following cerumen removal, an audiogram showed normal hearing sensitivity for the right ear, and a very mild (20 dB) sensory hearing loss in the 4000-Hz region for the left ear (Figure 3). Immittance findings (tympanograms and acoustic reflexes) were normal bilaterally. Word-recognition scores were 100% for each ear. Transient otoacoustic emissions (TEOAE) were recorded at normal amplitude and high (greater than 80%) reproducibility values for octave frequencies of 1000 Hz through 4000 Hz for the right ear. However, TEOAE were reduced in amplitude and reproducibility for frequencies above the 2000-Hz octave for the left ear (Figure 4), even though stimulus conditions (acoustic waveform, spectrum, and stability) were optimal, and overall response level (13.1 dB SPL) and whole reproducibility (94%) were within normal limits. The patient was fit with ER-15 musician earplugs.

During performances, he typically wore an ER-15 in his left ear to attenuate drum sounds (high hat, snare drum), but left the right ear unprotected so as to optimize his ability to hear the lead singer and other band members.

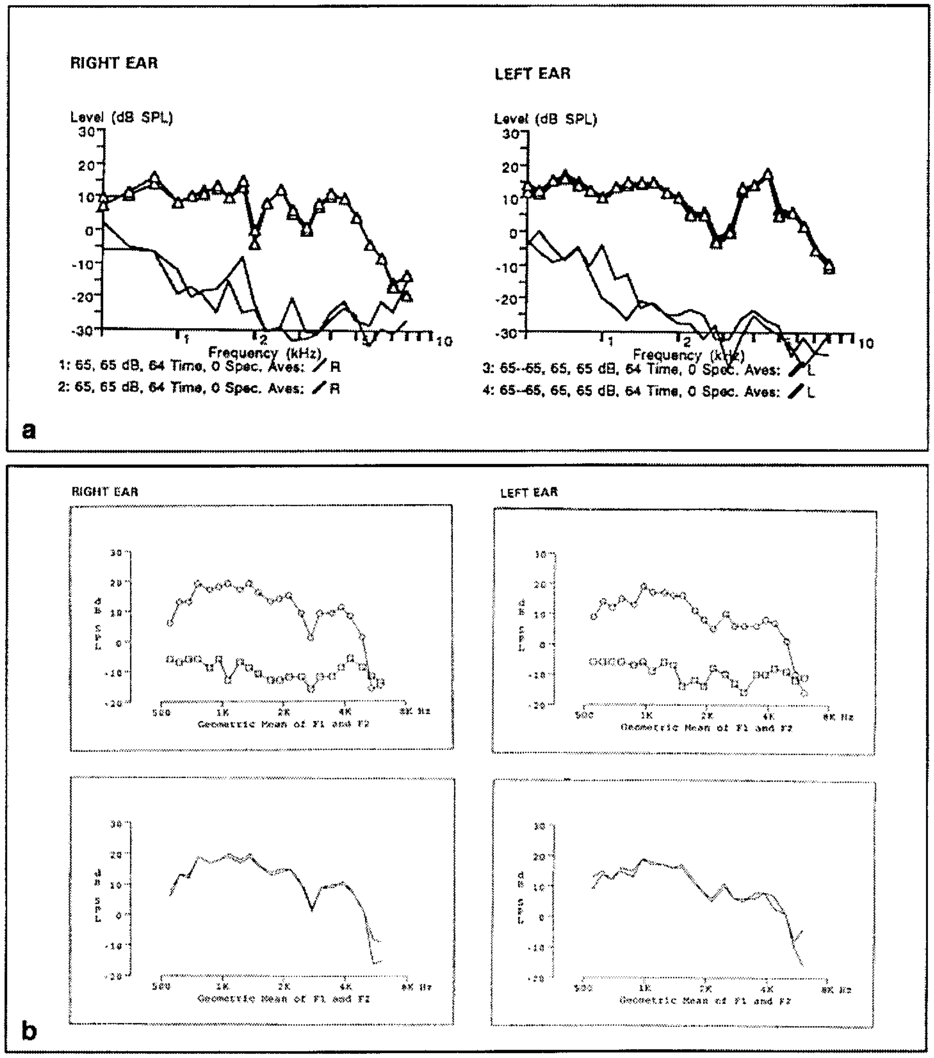

Figure 2a and 2b. Distortion-product otoacoustic emissions (DPOAE) for Case 1 as recorded for stimulus intensity levels of 65 dB SPL across the frequency region of 500 Hz through 8000 Hz with the Virtual Corporation 330 instrument (2a) and from 500 Hz through 5656 Hz with the Grason Stadler 60 instrument (2b). Reliably recorded DPgrams were within the clinic normative region for both of these DPOAE instruments, except for geometric mean stimulus frequencies higher than 5000 Hz. The audiogram for Case 1 is shown in Figure 1.

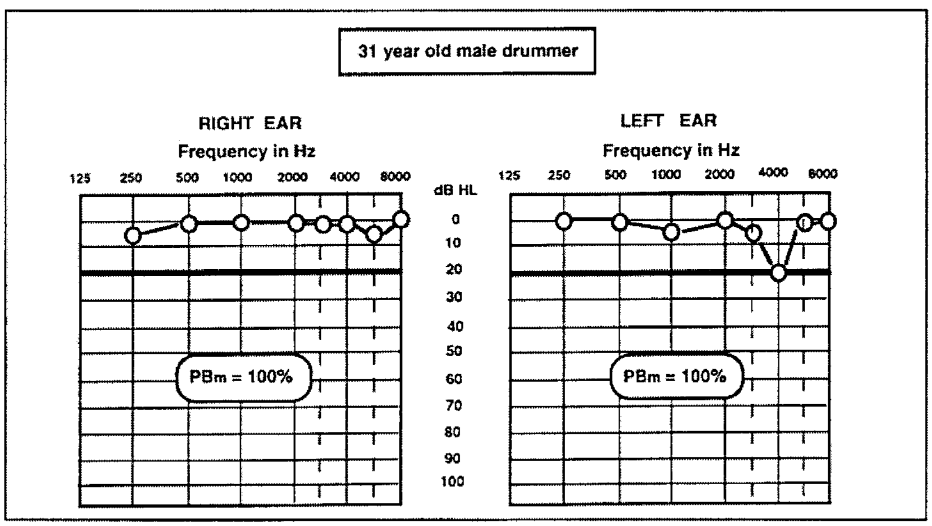

Figure 3. Audiogram for a 31-year-old professional drummer self-referred to the audiology clinic for fitting of ER-15 musician earplugs (Case 2).

Case 3: A Performer And Songwriter

A 47-year-old songwriter and performer with the two chief complaints of tinnitus and hearing loss was evaluated by audiology and otolaryngology. He reported a long history of exposure to high-intensity sounds as a member of a rock and roll band. His main professional concern was his increasing difficulty mixing music in the studio. Audiometric assessment revealed a notching sensory hearing loss for frequencies above 1000 Hz, greatest in the region from 3000 Hz to 4000 Hz (Figure 5). Word-recognition scores were good (90%) at an intensity level of 80 dB HL. Middle ear measurement by immittance and an otologic examination yielded normal findings.

DPOAE amplitude values were reliably recorded within the clinic normative region bilaterally for lower-frequency stimuli (geometric means of f_1 and f_2) at an intensity level ($L_1 = L_2$) of 65 dB SPL, but DPOAE were not recorded (equivalent to the noise floor) for geometric mean frequencies above 1590 Hz on the right ear and 1770 Hz on the left ear. These DPOAE geometric mean stimulus frequencies corresponded to audiogram frequencies for which his hearing loss exceeded 20 dB HL. Also, DPOAE amplitude fell well outside the normal region (less than 0 dB SPL) for frequencies with normal hearing thresholds that were adjacent to the lowest frequencies showing a pure-tone hearing loss (Figure 6). The patient was counseled and given information about tinnitus and ER-15 earplugs. Plans were made to perform sound level measurements in his studio. He was placed on a 6-month schedule for audiologic assessment.

Comments

These cases illustrate three distinct sets of audiometric findings. Case 1 represents the ideal audiologic scenario. The patient presented with no auditory complaints, and assessment of hearing sensitivity and otoacoustic emissions confirmed normal cochlear functioning.

By conventional audiometry, Case 2 had hearing sensitivity within clinically normal limits. However, otoacoustic emissions revealed that a very slight notching pattern to the audiogram for the left ear was, in all likelihood, a reflection of some outer hair cell dysfunction for frequencies above 2000 Hz. With an appropriate and flexible ear-protection strategy, this type of patient may preserve

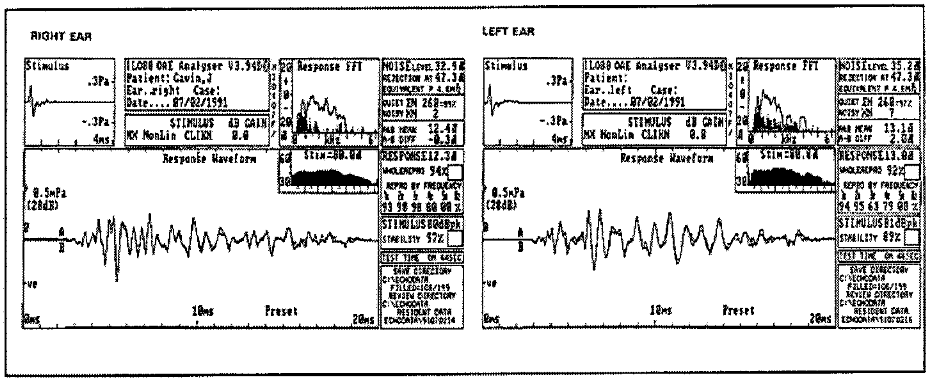

Figure 4. Transient evoked otoacoustic emissions (TEOAE) for Case 2 as recorded with the Otodynamics ILO 88 device. Note the decrease in TEOAE amplitude and reproducibility values for frequencies above 2000 Hz for the left versus right ears, corresponding to the audiometric

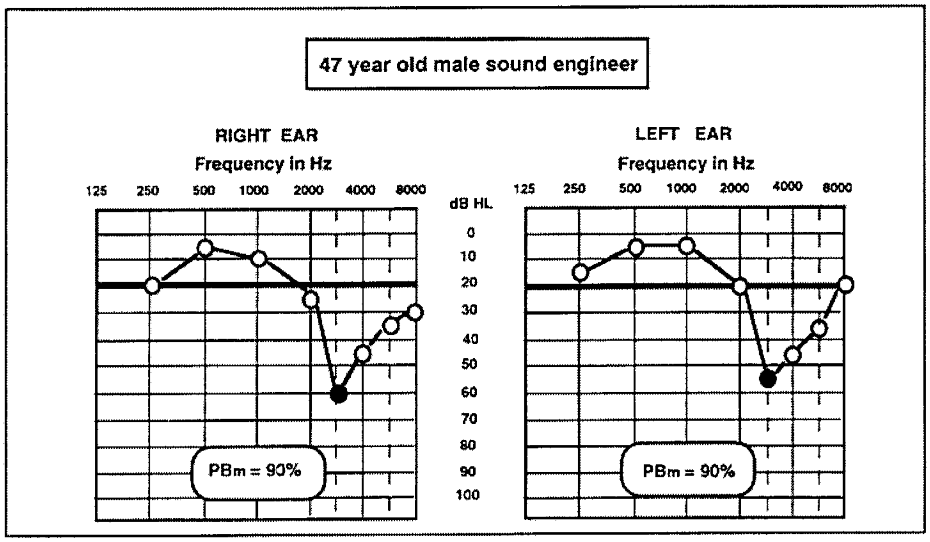

Figure 5. Audiogram for a 47-year-old songwriter and musician presenting to the audiology clinic with complaints of hearing difficulties and tinnitus (Case 3).

his remaining hearing function without limiting his professional activities.

Case 3, unfortunately, highlights the dangers of inadequate protection of the professional ear. Hearing sensitivity and word recognition remained adequate in most communication settings. However, the patient was acutely aware of a reduction in the perceived quality of music. He was experiencing serious difficulty performing one of his important professional responsibilities—mixing vocals and instruments during recording. In addition, he suffered from constant tinnitus. Otoacoustic emissions findings suggested severe outer hair cell dysfunction and, presumably, reduced frequency resolution for frequencies above about 1500 Hz.

STRATEGIES FOR HEARING CONSERVATION

Sound Attenuation

Monitoring sound levels. Music professionals must be taught the importance of limiting the intensity and duration of music exposure. For extended exposure during rehearsals and recording sessions, musicians should verify that sound levels do not consistently exceed 90 dB SPL. Higher levels during relatively brief periods (e.g., the final cut of a recording) pose no significant risk. In each work setting, someone should have primary responsibility for monitoring sound-intensity levels and the authority to limit the levels as indicated.

We provide music professionals with the following simple suggestions to prevent or minimize damage to their ears:

- Avoid exposure to sounds exceeding 90 dB whenever possible.
- Increase the distance between you and the source of high-intensity sounds.
- Wear appropriate sound-attenuating ear protection, such as earplugs specifically designed for musicians. These devices reduce the level of sound reaching your ear without distorting the quality of the music. Wear sound-attenuating ear plugs whenever you are exposed to loud sounds, including power tools, engines, and gunfire.
- Give your ears a rest for about 24 to 48 hours after exposure to high levels of sound.
- Have your hearing evaluated at least once each year by a licensed audiologist. The hearing evaluation should include measurement of hearing sensitivity (an audiogram) and also otoacoustic emissions (a measure of inner ear function).

ER-15 and ER-25 Musician Earplugs. Music professionals should routinely wear appropriate ear protection whenever they are exposed to potentially unsafe levels of music. Commercially available, custom-made earplugs designed by Etymotic Research for musicians offer adequate attenuation of sound without sacrificing the quality of music. Unlike most ear-protection devices used for attenuation of industrial and recreational noise, the ER musician earplugs have a relatively flat frequency response. Because they are custom-fit deep within the ear canal and include a passive filter device, the ER-15 (15 dB attenuation) and ER-25 (25 dB attenuation) earplugs combine comfort with a more natural sound.

A deep silicon earmold impression is required for both the ER-15 and the ER-25. Several commercial earmold laboratories manufacture the earplugs within a day or two after receiving the impressions. An inexpensive generic (non-custom) musician earplug (the ER-20) is also available from Etymotic Research.

Stage Monitors For Performances

To appreciate the complexity of the problem of excessive sound levels during live performances, one needs a basic understanding of how sound reinforcement is provided for both listeners and performers. Monitoring for live performances takes place in two separate areas. The public address system, the first monitoring system, provides the sound reinforcement for the audience (Figure 7). The house engineer, who is located in the center of the arena, controls the mix of this sound.

In the second monitoring system, the monitor engineer, who is usually located to the side of the stage, controls the sound mix. Stage monitors enable musi-

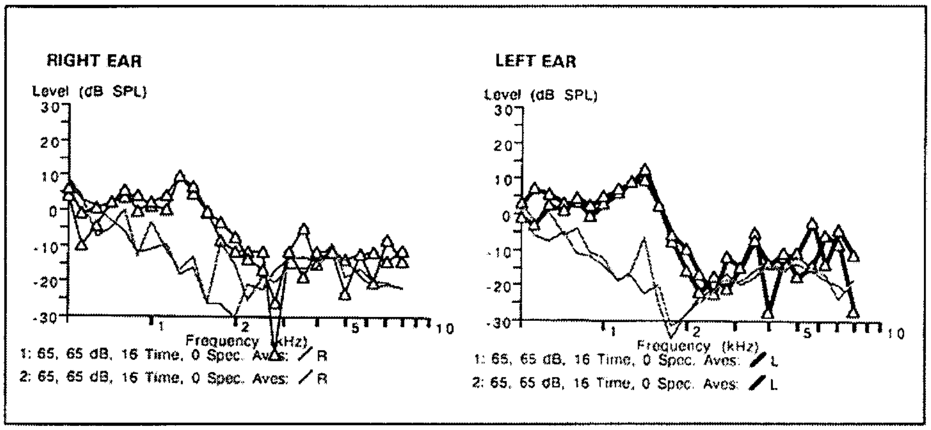

Figure 6. Distortion-product otoacoustic emissions (DPOAE) for Case 3 recorded bilaterally for stimulus intensity levels of 65 dB SPL across the frequency region of 500 Hz through 8000 Hz with a Virtual Corporation 330 instrument. Reliably recorded DPOAE were not observed for geometric mean stimulus frequencies higher than 1500 Hz. Clinically significant reduction in DPOAE amplitude was initially observed at 1590 Hz for the right ear and 1770 Hz for the left ear. Audiogram for Case 3 is shown in Figure 5.

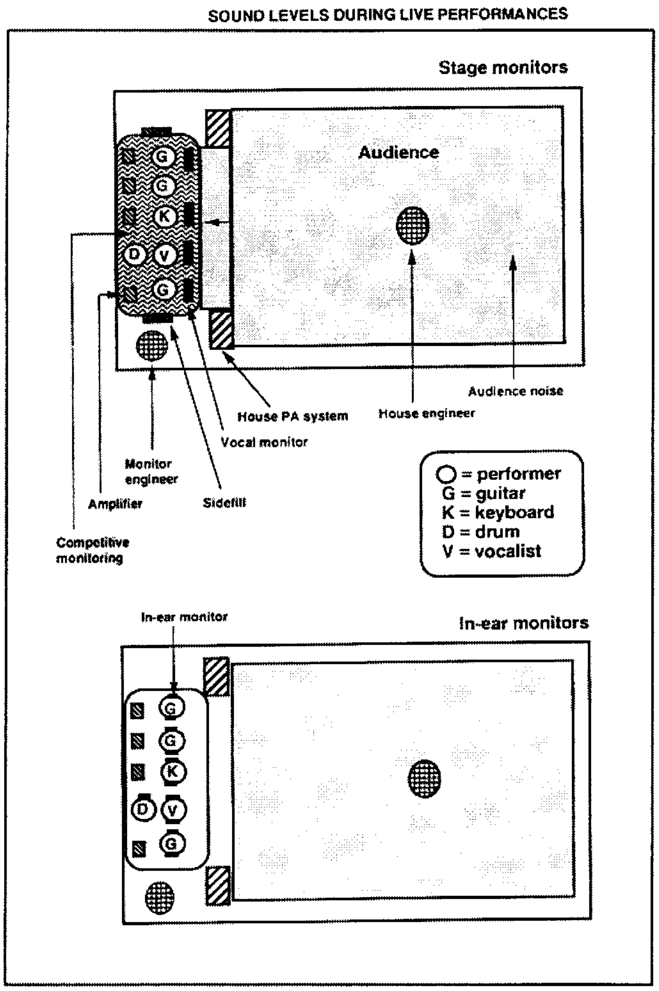

Figure 7. Schematic representation of sound sources and monitoring during live performance. The top panel illustrates high sound levels on stage produced by stage monitors (amplifiers and vocal monitors), sidefills, house PA system, and crowd noise. Competitive monitoring results when individual musicians increase amplifier and vocal monitor output in an attempt to hear their voice and instrument. Lower panel illustrates the reduction or attenuation of these stage sounds, and the elimination of competitive monitoring, by the use of in-ear monitors.

cians to hear their music through an entirely different mix from the house mix. The sound of each musician's instrument is enhanced by the amplifiers located behind them. In addition, vocal monitors are typically scattered across the front of the stage, while sidefills provide the mix of the entire band.

Performers face the problem of trying to hear and distinguish their instruments and voices within the barrage of sound from stage monitors, house PA system, and crowd noise (Figure 7, top panel). Frequently, one performer will tell the monitor engineer to increase the volume of his particular voice or instrument. That leads other band members to require further amplification of their voices and instruments. This is referred to as competitive monitoring. The unfortunate results of competitive monitoring are dangerously high sound levels and increased risk of tinnitus and hearing loss. Although high-fidelity passive hearing protection has gained well-deserved acceptance, it will not solve the problem of competitive monitoring.

In-ear Monitors

In-ear monitoring is changing the way live music is performed. By wearing high-fidelity, miniature speakers in deep-insertion custom earmolds, musicians can control the volume and frequency response of their own voice and instrument and balance them in relation to the rest of the band. The deep-insertion molds are necessary to isolate the ear from stage monitors, the house PA system, and ambient sound levels from the audience (Figure 7, lower panel). In-ear monitoring allows an artist to hear the full dynamic range of music without exposure to ear-shattering sound levels.

The ProPhonic IV in-ear monitor from Sensaphonics Hearing Conservation integrates the concepts of hearing conservation and superior sound quality. A super-soft silicone, custom earmold provides approximately 26 dB of isolation from external sound. The frequency response of the speaker, designed in conjunction with Etymotic Research, has been developed specifically for live performances. As with earplugs, the length of the mold must extend beyond the second bend of the ear canal to isolate the ear from external sound. An undersized ear impression will require higher sound levels from the in-ear monitors to overcome the ambient sounds leaking through the device.

Use of in-ear monitors can also effectively reduce the vocal fatigue and feedback that are commonly associated with singing through stage monitors. When singers turn up the volume from vocal stage monitors to hear their own voices better, feedback can result because of the proximity of the sound source to the performer's microphone. As a result, singers must push their voices harder to hear themselves, risking vocal fatigue and vocal nodules. Using in-ear monitors, singers may independently increase the volume of their voice and separate it from the band mix, thus reducing the risk of both hearing and voice disorders.

CONCLUSIONS

For professional musicians, early signs of hearing impairment secondary to overexposure to loud sounds often include alterations in their perception of music quality. Although these effects might go unnoticed by a nonmusician, they are a serious concern for the musician. In fact, at this early stage in sound- or music-induced ear damage, the effects may not always be detected as early as possible by simple audiometric tests of hearing sensitivity and speech discrimination. Yet, for the professional musician, it is very important to prevent the development of any hearing impairment, even "subclinical" auditory dysfunction.

From our experience, it appears that evoked OAE measurement may offer a sensitive measure of even subtle cochlear auditory dysfunction. Therefore, hearing professionals now have adequate tools for assessing cochlear function. With the advent of high-fidelity hearing protection and in-ear monitoring, we can also implement effective strategies for preventing music-related cochlear dysfunction. Finally, when a music-induced hearing impairment already exists, we must strive to minimize any further cochlear dysfunction while providing an appropriate audiologic management to the patient.

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