Personal Music Players:

Are We Measuring the Sound Levels Correctly?

by Elliott H. Berger, Susan C. Megerson, and M. E. Stergar

With the introduction of the Walkman® by Sony in the late 1970s, personal music listening habits were forever changed, only to be supercharged early in this century by Apple's iPod® players. The proliferation of personal music players (PMPs) is a cultural change that raises concern because of the tremendous quantity of audio stimulation that users—especially children—can now regularly introduce to their ears.

Much has been reported about the use of PMPs in the scientific and trade literature as well as in the popular media. A Google search for the 12 months from January 2008 to January 2009 for the terms "warning music 'hearing loss'" yielded 19,000 hits. Although a number of these hits represented measured information and advice, many included dire predictions such as this 2009 headline from News.Com.Au: "Experts warn of MP3 player hearing loss 'catastrophe.'"

The purpose of this article is to provide a factual basis to assess the potential risks of PMP use by offering guidance on how audiologists can accurately measure PMP sound levels to estimate realistically the risk of hearing damage. The sidebar and Figure 1 on page 15 summarize the potential risks of PMP use relative to other noisy activities for young people. Regardless of whether an audiologist chooses to measure earphone outputs, it is important to understand the relative risk of music listening so that clients may be counseled appropriately.

Although PMPs may not be the bane of young people's hearing, these devices can be played too loudly, too long, and too often. Indeed, studies indicate that most of these devices are capable of producing high sound levels (Fligor & Cox, 2004; Keith et al., 2008; Portnuff & Fligor, 2006). Investigations of typical PMP listening levels suggest that most users adhere to safe levels, although there is evidence that a small percentage do not. Some young people (estimates vary widely) play PMPs at sound levels of 85 dBA or greater especially when background noise is present, using higher volume settings with louder background noise (Airo et al., 1996; Fligor & Ives, 2006; Portnuff et al., 2009). One mitigating factor in the presence of background noise is earphone type. Listeners tend to choose lower output levels in noisy environments when using sound-isolating earphones (Fligor & Ives, 2006).

Only a handful of studies have attempted to factor in PMP use times, which are needed to estimate eight-hour equivalent average exposures. These results suggest that about 15% to perhaps as many as 25% of users would be expected to have exposures equal to or exceeding 85 dBA on an occasional or routine basis (Airo et al., 1996; Portnuff et al., 2009; Williams, 2005). Of concern is that the rate of PMP use is on the rise. Average listening time has increased over the past 20 years, from about 40 minutes per day in the 1980s to an hour per day in the 1990s to two hours per day in this decade (Ahmed et al., 2006; Airo et al., 1996; Bradley et al., 1987; Felchlin et al., 1998; Passchier-Vermeer, 1999; Rice, Rossi, & Olina, 1987; Torre, 2008; Williams, 2005).

Although hearing risk from PMPs may not be a widespread public health concern, further research is underway. It is important for hearing professionals to identify those individuals who are at risk by accurately measuring PMP sound levels to assess more sensibly the likelihood of hearing damage.

Accurate Measurement of Earphone Sound Levels

Measurement of sound levels is easy today because of the wide array of instrumentation available from consumer-oriented suppliers and sophisticated instrument manufacturers. But correct measurement of sound levels—particularly for earphone devices—is another matter. The key to understanding the problem is related to the transfer function of the open ear (TFOE), also referred to as the head-related transfer function (HRTF). Because of resonances of the ear, sound levels at the eardrum will be higher than those measured outside the ear (see Figure 2 on p. 16).

Sound levels generated by earphones are often measured by placing the earphones on an ear simulation device, such as an artificial head with representative ear canal or perhaps an audiometric earphone coupler. The levels reported are those at the microphone diaphragm in the ear canal, represented by point A in Figure 2. However, noise hazard, which is based on the relationship between sound levels and noise-induced hearing loss (NIHL), has historically been measured at point B. This disparity is the result of noise-damage criteria derived from studies conducted in the 1960s, when workers in industrialized countries were exposed to noise without the benefit of hearing protection, substantially complicating the matter of estimating effective noise exposure at the ear. At that time, standard practice was to position a sound-level meter in the workplace and record the levels at the worker's location in the absence of the worker. Today's miniature

*See **Personal Music Players** page 16*

Are Young People at Risk from Personal Music Players?

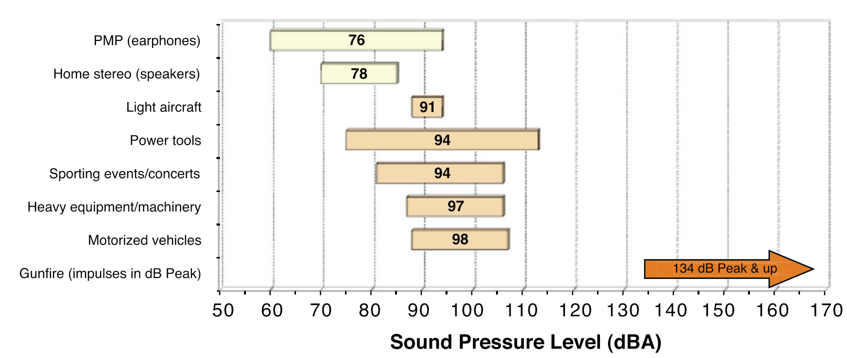
Contrary to popular beliefs and media reports, the hearing of young people in the United States does not appear to be worse than that of the prior generation. Recent large-scale studies of youth entering the workforce indicate that average hearing levels are the same as, or better than, those of young people 20–30 years ago (Harrison, 2008; Hoffman et al., 2006; Rabinowitz et al., 2006). Similarly, controlled epidemiologic studies of school-aged children show that average hearing levels among 6- to 19-year-olds in the 1990s were the same or better than children evaluated two decades earlier (Holmes et al., 2004).

Although there are many potential culprits for ear and hearing difficulties, surveys have found that young people routinely experience a great variety of noise sources, many potentially hazardous (Danhauer et al., 2009; Neitzel & Meinke, 2006; Rabinowitz et al., 2006; Smith et al., 2000). Individual susceptibility to noise is paramount—but not quantifiable—with the current state of the art. Other key factors that influence hearing risk include the level of the sound and the duration and frequency of exposure (how loud, how long, and how often).

Risk criteria for damage are based on the concept of increased risk with increased dose, a function of the how loud and how long part of the equation. According to the 1998 risk criteria suggested by the National Institute of Occupational Safety and Health (NIOSH), which are commonly used to calculate hearing risk due to both occupational and recreational noise, a "risky" noise exposure is considered to be an average sound level of 85 dBA for an eight-hour duration. Using NIOSH's 3-dB doubling rate for estimating equivalent risk, an eight-hour exposure to average sound levels of 85 dBA is considered to be roughly comparable to 88 dBA for four hours, 91 dBA for two hours, 94 dBA for one hour, and so on.

Recent research evaluating typical listening levels and usage time suggest that few young people are at substantial risk of hearing loss from PMP listening (Airo et al., 1996; Portnuff et al., 2009; Williams, 2005). A greater risk is posed by recreational activities with higher average sound levels, such as hunting/target shooting; using power tools; operating motorized vehicles such as motorcycles, snowmobiles, and ATVs; and attending noisy sporting events and concerts. Gunfire, in particular, is considered to be the most onerous noise hazard, posing high risk of

Figure 1. Range of Typical Sound Levels for Various Recreational Noise Sources



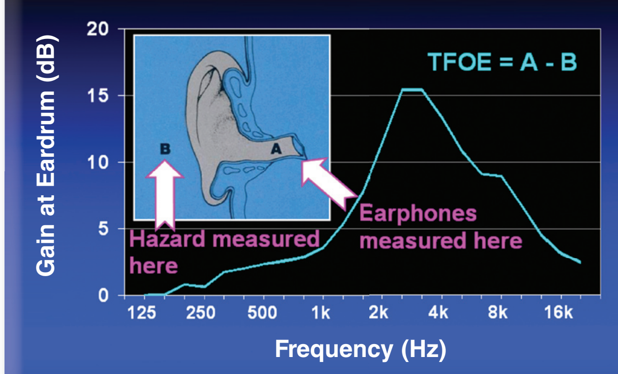
Range of typical sound levels for common recreational noise sources, arranged in order of increasing average sound level. The mean value for range is shown in each bar. PMP and Gunfire compiled from authors' review of literature; all other categories as reported in Neitzel et al., 2004.

permanent hearing loss and even the possibility of instantaneous hearing damage. Figure 1 summarizes typical sound level ranges for several common sources of recreational noise.

Although the range of sound levels varies, average levels are much lower for music listening (either via home stereo speakers or PMPs with earphones) than for many other sources of leisure noise. As an example, using NIOSH's 3-dB doubling rule for estimating risk, a music listener would need to be exposed to typical PMP sound levels for 16 hours (average sound level of 76 dBA) to equate to a 15-minute exposure to power tools (average sound level of 94 dBA).

An additional aspect of assessing hazardousness of PMP and leisure noise is that the most common source of substantial hearing risk is noisy occupations in which individuals are often exposed to louder sounds, for longer hours, and more often than they are to recreational noise. Recent studies of young construction workers, for example, indicate that the majority of these individuals' total noise exposure is a consequence of occupational, not recreational, sources (Neitzel et al., 2004).

Figure 2: Transfer Function of the Open Ear



The increase in the sound pressure levels measured at the eardrum due to the transfer function of the open ear.

***Personal Music Players** from page 15*

microphones and ear- or shoulder-mounted instruments, such as dosimeters, were unavailable. Thus risk was, and still is, based on measurements at B, whereas PMP levels are measured at point A.

Because of the ear's natural amplification characteristics, primarily its ¼ wavelength ear canal/tube resonance, the levels in the 2–4 kHz frequency range measured at point A are more than 10 dB greater than those in the undisturbed sound field, measured at point B. Thus, reporting eardrum or coupler sound-pressure levels can substantially overestimate the hazard of sounds, such as music, that contain substantial high-frequency content.

The preferred method of measuring earphone systems is described in an international standard on the determination of sound immission for sound sources placed close to the ear (ISO 11904, Parts 1 and 2), and a European standard on measuring the sound levels from earphones used with sound system equipment (EN 50332). These methods utilize an occluded ear simulator, a version of which is incorporated into acoustical manikins such as the well-known KEMAR (Knowles Electronic Manikin for Acoustic Research) shown to the left in the photo on p. 14. The manikin comprises a head and torso with anatomically correct and flexible ear simulations (including the pinna and concha), a cylindrical metal ear canal, and a specially designed acoustic coupler in which the microphone is placed at the termination of the ear canal. Even with this device, care should be taken to correctly position the earphones to reproduce the type of fit found on human ears. Sound-level measurements are critically affected by the earphone fit and seal, especially when the earphone has an earplug-like tip that enters the ear canal (insert) or caps the canal at its entrance (earbud) (Keith et al., 2008). When you fit earphones on your own ears, you can easily hear differences in sound quality and fullness of the bass as you change the earphone fit and seal.

The test signal should also be considered in the measurement of output levels. Signals representative of those listened to by typical PMP users are best for validity of the data, but they can be difficult and time-consuming to measure because of their moment-to-moment variability. Therefore, a stationary test signal such as a shaped pink-noise spectrum is generally employed. The noise is tailored to a frequency spectrum representative of music or speech. One standardized spectrum is the IEC test signal (IEC, 1985) that compares favorably with actual representative music spectra (Keith et al., 2001). Once the measurements are recorded, they are A-weighted (dBA) to properly reflect hearing risk. The second key step is to transform the ear canal measurements to values suitable for noise-hazard analysis, i.e., equivalent sound field. This transformation is done by subtracting the TFOE values, frequency by frequency, from the eardrum-equivalent values that were recorded. Without the TFOE correction, as will be shown below, the measured values would substantially overstate the true noise risk by as much as 15 dB.

Casual Estimates of Sound Levels

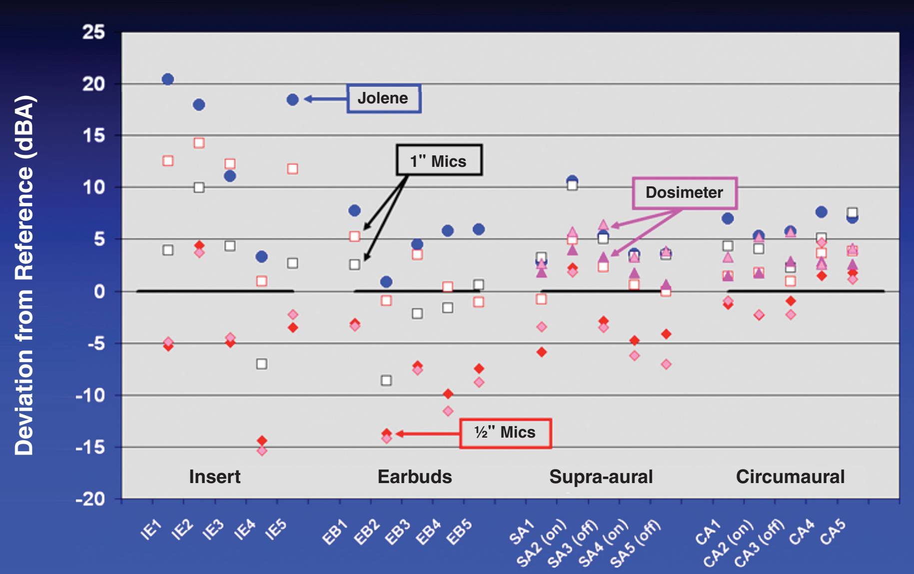
Because acoustical manikins are often not available, efforts have been made to estimate sound levels of PMPs in other ways. Such "casual" measurements of earphone levels have frequently been reported in the literature and the media. Measurements have been taken by holding a microphone next to the earphone and inappropriately using those values to represent the risk. Laboratory measurements have been reported that were done incorrectly with inappropriate couplers, or with couplers or probe microphones but without the requisite TFOE corrections. These data appear in some of the earliest publications on the topic of PMPs (Katz et al., 1982) as well as recently in otherwise quite well-conceived studies (Torre, 2008).

One popular approach to estimating sound levels of PMPs is the Jolene manikin (shown to the right in the photo on p. 14), which is intended to educate youth about safe-listening practices. This inexpensive home-built test device is made from a department store manikin and a Radio Shack sound-level meter. Her construction and use is described in *The Jolene Cookbook* (Martin & Martin, 2007), available for free download at **www.dangerousdecibels.org**.

Errors in Casual Measurements

In our experiments, we compared the preferred measurement approach using an acoustic manikin (and transformation of those values using TFOE) to casual measurements with simplified manikins, or no manikin at all and no TFOE correction. We measured the output levels of PMPs with five different insert earphone systems (such as the Etymotic ER6), five earbud-type systems that seal at the entrance of the ear canal (such as the Apple In-Ear

Figure 3: Error re: TFOE-corrected KEMAR values



Measurements of earphone sound levels using hand-held microphones, dosimeter microphones, and a Jolene manikin compared to a reference standard laboratory procedure utilizing a KEMAR manikin with an ear coupler.

Headphones), three supra-aural devices that rest on the pinna (two of which included active-noise reduction and were tested in the on- and off-modes), and four circumaural devices that seal around the pinna against the head (one of which was an active noise reduction device and tested in its two modes).

We took measurements with two different half-inch and two different one-inch microphones held directly against the earphone diaphragms, with small dosimeter microphones in the ears under the devices in two different orientations (for the supra-aural and circumaural earphones) using Jolene; we also took measurements with a few devices (data not shown in Figure 3 on p. 16) with a standard earphone coupler used for audiometer calibration (NBS-9A). These values, without any TFOE corrections, were compared to what was considered "truth," i.e., data measured using KEMAR with soft pinna and TFOE corrections. For the KEMAR measurements, the microphone output was monitored by the third author while he adjusted the earphones for best fit.

The results are presented in Figure 3, grouped by earphone type. The vertical axis represents the error in the measurement of the overall A-weighted sound level of the IEC-shaped pink noise, compared to the "truth," the TFOE-corrected KEMAR measurements (i.e., a positive result indicates that the casual method overestimated the actual sound field equivalent level). For the supra-aural and circumaural devices all methods agreed within ± 5 dB, except in one instance in which the one-inch microphone data were high by 10 dB. For the earbuds, the spread was greater with overestimates generally no more than 5 dB, but with one underestimate of almost 15 dB. The insert earphone data were the most variable with errors of + 20 to -15 dB.

When viewing the Jolene data in this chart, note that the instructions for this device suggest a 5-dB TFOE correction (subtraction from measured level), which was not made for the data in this figure. In fact a 5-dB correction would closely align Jolene with the "truth" except for the insert earphones. This result was due to Jolene's ear canal, which is short and does not allow for correct insertion of such devices. Thus, she is a fine teaching tool, but her use for determining risk of insert earphones is problematic.

The hearing risks of excessive noise exposure have become increasingly publicized in the past decade. As PMP utilization pervades the culture, warnings about their hazard become more strident. In this report we endeavored to place the risk of PMP exposures in perspective compared to other noisy recreational activities, and to provide guidance on the accurate measurement of the sound levels they create.

It is certainly laudable to educate our youth about the potential risks of PMPs, but exaggeration can diminish our credibility and divert attention from what are arguably more hazardous noisy activities. All efforts to quantify risk of hearing loss from various noise sources, including PMP use, must be based on accurate measurements of both the levels and durations of exposure.

Based on our studies, we recommend the following:

- Use accurate equipment (such as acoustic manikins) and standardized protocols (ISO 11904) for measuring output sound levels of all PMPs (and earphone types) when data are critical for research purposes or litigation.
- Coupler/eardrum/manikin measurements must be TFOE-corrected; otherwise overestimates of 4–8 dB will occur when using resulting sound levels to predict hearing risk.
- Hand-held mics can over- or underestimate levels by as much as 15 dB for insert and earbud devices, but are within about 5 dB for supra-aural and circumaural devices.
- Jolene is a fine teaching tool and her suggested 5-dB TFOE correction is suitable for all types of earphones except insert earphones, for which she is not applicable.

Selected References

Holmes, A., Niskar, A. S., Kieszak, S., Rubin, C., & Brody, D. (2004). Mean and median hearing thresholds among children 6 to 19 years of age: The third National Health and Nutrition Examination Survey, 1988 to 1994, United States. *Ear and Hearing, 25*(4), 397–402.

International Organization for Standardization (2004). *Acoustics—Determination of sound immission from sound sources placed close to the ear—Part 2: Technique using a manikin* (ISO 11904-2:2004). Geneva, Switzerland: Author.

Keith, S. E., Michaud, D. S., & Chiu, V. (2008). Evaluating the maximum playback sound levels from portable digital audio players. *Journal of the Acoustical Society of America, 123*(6), 4227–4237.

Martin, G. Y., & Martin, H. W. (2007). *The Jolene Cookbook.* Portland, OR: Oregon Health and Science University, **www.dangerousdecibels.org.**

Additional references for this article can be found at *The Leader Online.* Search on the title of the article.

Elliott H. Berger, MS, *is a senior scientist, auditory research, at 3M, E•A•RCAL[SM] Laboratory, (Indianapolis, Ind.), where for more than 30 years he has studied noise and hearing conservation with an emphasis on hearing protection. He chairs the ANSI working group on hearing protectors and has been lead editor for two highly regarded texts on noise and hearing conservation. His recent research has focused on methods of measuring earphone levels and earphone systems. Contact him at Elliott.Berger@mmm.com.*

Susan C. Megerson, MA, CCC-A, *is an audiologist in the Hearing and Speech Department at the University of Kansas Medical Center, specializing in hearing conservation. She has served as ASHA's liaison to and chair of the Council for Accreditation in Occupational Hearing Conservation. She is a past president of the National Hearing Conservation Association (NHCA) and serves on the NHCA Scholarship Foundation's Board of Directors. Contact her at smegerson@kumc.edu.*

Michael E. Stergar, *an acoustics technician at 3M, Electroacoustic Sound Laboratory, (Indianapolis, Ind.), evaluates a variety of electronic products and develops new test methods. Contact him at Mike.Stergar@mmm.com.*