Noise Exposure: Explanation of OSHA and NIOSH Safe-Exposure Limits and the Importance of Noise Dosimetry

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INTRODUCTION

It's a noisy world, and hearing damage from loud sound affects millions of people. Noise-induced hearing loss (NIHL) and associated disorders of tinnitus, hyperacusis and diplacusis are all irreversible. This is a tragedy, considering that these often debilitating conditions are preventable. The keys to prevention are in understanding the risks and consistently acting to minimize the risks.

NEW EVIDENCE FOR URGENCY

NIHL and associated disorders (which, for simplification, will be included in the acronym "NIHL") are caused by overexposure: listening to sound that's too loud, for too long. NIHL can occur from a single activity such as an explosion or a loud concert, but it usually occurs gradually over many years. Decades of data have shown that noise-related shifts in hearing appeared to be temporary, a phenomenon known as temporary threshold shift (TTS). With TTS, hearing thresholds typically recover to pre-noise exposure levels after a period of auditory quiet. Because of this recovery, many of us assumed that the structure and function of the auditory system was affected only temporarily by noise, returning to normal (or pre-exposure) levels after a period of quiet. We believed that permanent changes in auditory anatomy transpired only after repeated auditory insults occurring over many years. However, research on noise exposure in animal models by Kujawa and Liberman (2009) challenges these assumptions.

Kujawa and Liberman (2009) found that while outer hair cells do recover post-exposure (with a corresponding recovery of hearing thresholds and otoacoustic emissions [OAEs]) other changes in the basal region of the cochlea do not recover: there is dramatic degeneration of both pre- and post-synaptic elements of the inner hair cells and spiral ganglion cells. Not only is this damage undetectable using current test protocols (pure tone thresholds, OAEs and Auditory Brainstem Response [ABR]) but the loss of spiral ganglion cells is not seen until weeks or months post-exposure. Kujawa and Liberman suggest that noise-induced hearing damage has progressive consequences that may not manifest until much later. This damage may be expressed as difficulty hearing in noise and/or in associated auditory disorders (tinnitus, hyperacusis, etc.).

The implication of this research is that noise can produce subclinical damage that goes undetected, progresses unnoticed, and finally manifests itself long after the fact. We can't measure this subclinical damage using audiometric tests, including the "gold standard" for testing NIHL: pure tone hearing thresholds. Data collected over many years from persons exposed to industrial noise shows that most NIHL develops over the first 10-15 years of noise exposure and then asymptotes (levels off). From a preventive standpoint, the sooner we identify hearing risk and minimize it, the better. We need to educate our young people and equip them to protect their hearing at an early age, ideally before damage occurs. To do this we must monitor noise exposures to assess risk and use hearing protection when necessary to reduce the risk of NIHL.

WHO GOVERNS NOISE EXPOSURE?

In the United States, concern with noise exposures began primarily in the workplace. Guidelines for occupational noise exposure were established by the Occupational Safety and Health Administration (OSHA, 1983) and the National Institute for Occupational Safety and Health (NIOSH, 1998). Both OSHA and NIOSH were created by the Occupational Safety and Health Act of 1970 (see www.cdc.gov/niosh/about.html).

OSHA is part of the U.S. Department of Labor and is responsible for developing and enforcing workplace safety and health regulations. The OSHA standard (29CFR1910.95) carries behind it the force of law and employers in the industrial sector are bound to comply with it. Those employed in mining, railroad, coast guard, military, and construction are bound by their own standards.

NIOSH is part of the Centers for Disease Control and Prevention (CDC) in the U.S. Department of Health and Human Services. NIOSH conducts research and provides information, education, training, and recommendations regarding occupational safety and health. As such, NIOSH is in a position to recommend standards and best practices, but it is not in a position to regulate or enforce standards.

LIMITING NOISE EXPOSURE: DAMAGE-RISK CRITERIA

How long and how loud can we listen to sound without risking hearing damage? Damage-risk criteria provide the basis for recommending noise exposure limits based on noise level and exposure time. OSHA and NIOSH criteria are shown in Figure 1.

Level, in dB A	85	88	90	92	94	95	100	105	110	115
OSHA PEL	16		8			4	2	1	0.5	0.25
NIOSH REL	8	4			1		0.25			

Figure 1. Duration (in hours) of allowable exposures based on OSHA and NIOSH criteria. PEL = Permissible Exposure Limit; REL = Recommended Exposure Limit. Noise exposure levels/times exceeding those shown in Figure 1 require the use of hearing protection.

OSHA permits exposures of 85 dBA for 16 hours per day, and uses a 5-dB time-intensity tradeoff: for every 5 dB increase in noise level, the allowable exposure time is reduced by half. For every 5 dB decrease in noise level, the allowable exposure time is doubled. All time/intensity values shown on the OSHA PEL line in Figure 1 are assumed to have equal risk to each other, that is, 16 hours at 85 dB carries the same auditory risk as 8 hours at 90 dB, 4 hours at 95 dB, 2 hours at 100 dB, and so on.

NIOSH recommends an exposure limit of 85 dBA for 8 hours per day, and uses a 3 dB time-intensity tradeoff: for every 3 dB increase in noise level, the allowable exposure time is reduced by half. For every 3 dB decrease in noise level, the allowable exposure time is doubled. The time/intensity values shown on the NIOSH REL line in Figure 1 are assumed to have equal risk to each other, that is, 8 hours at 85 dB carries the same auditory risk as 4 hours at 88 dB, 2 hours at 91 dB, and so on.

The differences in OSHA criteria and NIOSH recommendations for exposure limits produce different outcomes: the more lenient OSHA values allow for higher exposures for longer durations and the more conservative NIOSH values recommend lower exposures for shorter durations. The NIOSH values are based on scientific studies relating noise exposure to hearing loss, and are more protective of hearing. It should be noted that both standards are based on the assumption that the noise occurs as part of a work environment, and both assume non-occupational quiet. That is, the limits are based on an 8-hour workday, five days per week over a 40-year working lifetime, and the time the individual is not at work (the other 16 hours in a day, as well as weekends) is assumed to be quiet. The standards do not account for noisy activities and hobbies (e.g., concerts, ATVs, snowmobiles, power tools, car races, live music, etc.) which may increase risk for NIHL.

ORIGIN OF DAMAGE-RISK CRITERIA

The NIOSH Recommended Exposure Limit (REL) is based on scientific data relating noise-induced permanent threshold shift (NIPTS) to the level and duration of noise exposures (NIOSH, 1998). In contrast, the OSHA Permissible Exposure Limit (PEL) was the result of debate and compromises that are a part of enacting any legislation (OSHA, 1983). Neither guideline is completely protective in nature; both allow for some NIPTS based on their individual definitions of material hearing impairment and the percentage of the population for whom this risk is deemed acceptable. Additionally, standards are based on average risk (rather than individual susceptibility) so certain individuals may be at greater or lesser risk for developing NIHL.

Definition of Material Hearing Impairment

The time/intensity limits comprising the OSHA PELs and NIOSH RELs are in part based on each organization's definition of material hearing impairment and the excess risk of developing that impairment.

OSHA defines material hearing impairment as average hearing thresholds exceeding 25 dB HL at 1k, 2k and 3k Hz, bilaterally. NIOSH uses the same definition, except that thresholds at 4 kHz (where the effects of noise are usually seen first and/or worst) are included. The inclusion of 4k Hz is an improvement over the OSHA definition; however, the averaging of thresholds across frequencies and ears means that significant hearing loss can occur before either formula labels it as hearing impairment. The audiogram shown in Figure 2 reveals a mild to moderate high-frequency hearing loss, but this audiogram does not meet the definition of material hearing impairment under either the OSHA or NIOSH standards.

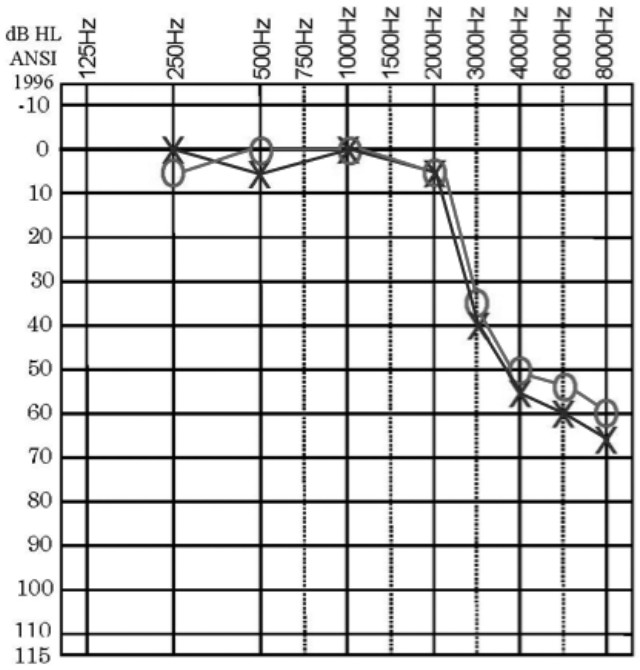

Figure 2.

Both OSHA and NIOSH definitions include 1k and 2k Hz, where NIHL is not likely to be seen. This has the effect of "watering down" the average loss across frequencies. In the presence of normal low-to- mid frequency hearing, there must be moderate to moderately-severe high frequency hearing loss in both ears to produce a 3-frequency or 4-frequency average exceeding 25 dB. Significant hearing loss can occur before it is labeled as such by these definitions.

Excess risk

Excess risk is defined as the percentage of people in a noise-exposed population who develop a material hearing impairment (as defined by OSHA or NIOSH) above and beyond the percentage of people in a non-noise-exposed population who develop a material hearing impairment. Excess risk is calculated based on the exposure level and assumes an 8-hour work day, 5 days per week, over a 40-year working lifetime. Figure 3 shows the excess risk of developing material hearing impairment for different exposure levels, based on the NIOSH definition of material hearing impairment.

Exposure Level (8-hr time-weighted average)	Excess Risk
80 dB A	1%
85 dB A	8%
90 dB A	25%

Figure 3. Excess risk of developing material hearing impairment as a function of daily noise exposure (assuming a 5-day work week) over a 40-year working lifetime

As can be seen in Figure 3, a 90 dB exposure incurred 8 hours per work day over a working lifetime, results in 25% excess risk of developing material hearing impairment, while an 85 dB exposure results in 8 % excess risk of developing material hearing impairment. While neither criterion protects all workers, the NIOSH limit of 85 dB is more protective and if followed, results in fewer workers sustaining material hearing impairment.

Individual susceptibility

Individual susceptibility for NIPTS depends on genetic predisposition ("tough ears" vs. "tender ears"), environmental contaminants (e.g., chemicals and solvents), medications (e.g., chemotherapy or antibiotic agents that react synergistically with noise and exacerbate NIHL), medical conditions (e.g., diabetes, heart disease) and behaviors (e.g., smoking). Environment, health and lifestyle issues, combined with occupational and non-occupational noise, determine an individual's risk for developing NIHL. An individual could adhere to the limits of the more conservative NIOSH recommendations and still develop NIHL due to individual risk factors that can't be accounted for in standards.

In summary, both the OSHA and NIOSH limits seek to reduce risk for the average person, rather than to prevent NIHL for all individuals.

MEASURING NOISE EXPOSURES

To assess risk of NIHL we need to know the level and duration of noise exposures so we can compare them to the RELs. Noise can be measured using a sound level meter or a noise dosimeter.

A sound level meter measures sound level at a single point in time, which is useful when sound is steady-state with little variation in level. Sound level meters are inexpensive, widely available, and relatively simple to use. When sound exposures vary in level and duration it's difficult to accurately estimate exposure using a sound level meter, and a noise dosimeter should be used instead.

A noise dosimeter measures sound levels continuously over time and integrates them into a single value, the noise dose. A dosimeter provides a more accurate estimate of noise exposure when sound levels fluctuate and/or exposure durations vary, and can alert the user in real time to the need for hearing protection based on the accumulated noise dose. Noise dosimeters have traditionally been expensive and complicated to operate, limiting their use to special applications by highly trained individuals. Etymotic Research, in collaboration with Greg Flamme, Ph.D., developed two low-cost personal noise dosimeters that are easy to operate and can be used for a wide variety of applications.

NOISE DOSE

Noise dose is expressed as a percentage of a predetermined maximum, defined by the standard you choose (e.g., OSHA or NIOSH). Dose is calculated based on the criterion level, threshold level and exchange rate. Criterion level is the sound level which, if continuously applied for 8 hours, would result in a 100% noise dose. Threshold level is the level below which the dosimeter produces no noise dose accumulation (values below that level are effectively considered to be zero). Exchange rate is based on the equal-energy hypothesis, which assumes that equal amounts of sound energy will produce equal amounts of hearing impairment.

OSHA uses a criterion level of 90 dB, a threshold level of 80 dB, and an exchange rate of 5 dB. An OSHA 100% noise dose is 90 dB for 8 hours, 95 dB for 4 hours, 100 dB for 2 hours, and so on (OSHA decreases the PEL to 85 dB for 8 hours if the employee has a documented threshold shift; see 29CFR 1910.95 for additional details).

NIOSH uses a criterion level of 85 dB, a threshold level of 75 dB, and an exchange rate of 3 dB. A NIOSH 100% noise dose is 85 dB for 8 hours, 88 dB for 4 hours, 91dB for 2 hours, and so on (see Figure 1).

Since OSHA and NIOSH define dose differently, the first rule of interpretation is to know which standard the dose calculation was based on. As illustrated previously, the NIOSH and OSHA allowable sound levels and times differ, so each define a 100% dose differently (see Figure 4).

OSHA (1983)

Level (dBA)	Duration	Dose %
90	8	100
95	4	100
100	2	100
105	1	100
110	30 min	100
115	15 min	100

NIOSH (1998)

Level (dBA)	Duration	Dose %
85	8	100
88	4	100
91	2	100
94	1	100
97	30 min	100
100	15 min	100

Figure 4. Equivalent unprotected noise exposures (level over time) that produce a 100% noise dose.

The differences in the OSHA and NIOSH standards become noticeable at high noise levels: OSHA allows a 100 dB noise exposure for two hours, while NIOSH limits it to 15 minutes; OSHA allows a 115 dB noise exposure for 15 minutes, while NIOSH limits it to 28 seconds (not shown). These differences undoubtedly produce differences in risk for NIHL, with the OSHA criteria carrying higher risk. The exposure used by Kujawa and Liberman (2009) was 100 dB for 2 hours, which constitutes a 100% dose as defined by OSHA. This single exposure produced irreparable damage to IHC afferent nerve terminals and associated degeneration of the cochlear nerve.

An important point about noise dose is that it is cumulative; noise dose never decreases over time. While sound levels may go up and down over time, noise dose only increases or plateaus over time. This is because you can't remove the exposure once it has occurred, much the same way you can't undo sun exposure after the fact. When the combination of sound levels and duration exceed those shown in Figure 4, noise dose increases to values greater than 100% (see Figure 5).

OSHA (1983)

Level (dBA)	Duration	Dose %
105	1	100
105	2	200
105	4	400
105	8	800
105	16	1600

NIOSH (1998)

Level (dBA)	Duration	Dose %
94	1	100
94	2	200
94	4	400
94	8	800
94	16	1600

Figure 5.

A 200% noise dose is two times the allowable limit (equivalent to two days' worth of noise exposure); a 400% noise dose is four times the allowable limit (equivalent to four days' worth of noise exposure), and so on. Do exposures like this occur often enough for us to be concerned? Absolutely! Measurements taken during a drum line demonstration in the band room at a local high school, with only half of the drum line students resulted in a 1400% noise dose after only 45 minutes.

Using dosimetry results to recommend hearing protection

The simplest way to use noise dosimetry results is to recommend use of hearing protection whenever noise dose exceeds 50%, particularly if that dose is reached early in the noise exposure period. Initiating protection at a 50% noise dose is more protective, especially for individuals with higher than average susceptibility to NIHL. This also recognizes the potential for exposure to noise throughout the day, rather than limiting potential exposure to the work day only.

REFERENCES

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