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Leisure Noise and Hearing

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Prevention of Noise-Induced Hearing Loss from Recreational Firearms

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Abstract

In the United States and other parts of the world, recreational firearm shooting is a popular sport that puts the hearing of the shooter at risk. Peak sound pressure levels (SPLs) from firearms range from ∼140 to 175 dB. The majority of recreational firearms (excluding small-caliber 0.17 and 0.22 rifles and air rifles) generate between 150 and 165 dB peak SPLs. High-intensity impulse sounds will permanently damage delicate cochlear structures, and thus individuals who shoot firearms are at a higher risk of bilateral, high-frequency, noise-induced hearing loss (NIHL) than peer groups who do not shoot. In this article, we describe several factors that influence the risk of NIHL including the use of a muzzle brake, the number of shots fired, the distance between shooters, the shooting environment, the choice of ammunition, the use of a suppressor, and hearing protection fit and use. Prevention strategies that address these factors and recommendations for specialized hearing protectors designed for shooting sports are offered. Partnerships are needed between the hearing health community, shooting sport groups, and wildlife conservation organizations to develop and disseminate accurate information and promote organizational resources that support hearing loss prevention efforts.

Keywords: Impulse noise, firearms, noise-induced hearing loss, hearing loss prevention, hearing conservation, hearing protection

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Learning Outcomes: As a result of this activity, the participant will be able to (1) identify acoustic and behavioral factors that influence the risk of auditory damage from recreational firearm impulse noise exposures; (2) describe hearing loss prevention strategies for individuals exposed to impulse noise from recreational firearms.

In the United States, millions of individuals across all ages shoot firearms for sport. Although less popular in other countries, recreational hunting or target shooting presents the most serious and immediate threat to hearing when compared with other leisure activities. Participation in firearm-related sport jeopardizes not only the hearing of the shooter but also others nearby (instructors, spectators, athletes). Although the potential for auditory damage from high-level impulse noise has been recognized for over a century, our understanding of the magnitude of the firearm-related risk, factors influencing the risk, and effective strategies to prevent hearing loss and tinnitus continues to advance. In this article, we draw from our own work and the extensive literature on recreational shooting to outline the risk of hearing damage from exposure to firearm noise, describe various factors that influence the risk, and detail protective strategies that shooters can adopt to minimize the risk.

Recreational Shooting

Civilians are estimated to own ~650 million firearms worldwide. [1] Firearms are used for sport while hunting, target shooting, competitive shooting, reenacting historical events, entertaining, fund-raising, scouting, and officiating in athletic events (i.e., track and field, swimming). It is estimated that ~46% of adult males and 13% of adult females in the United States have fired a gun at some point in their life (Flamme, unpublished analysis of data from the 2007 U.S. National Health Interview Survey). Increases in the number of U.S. women engaged in firearm-related sports were found between 2001 and 2013. [2] The number of female hunters increased from 1.8 to 3.5 million (85% increase) and women target shooters increased from 3.3 to 5.4 million (60% increase). The number of individuals participating in firearm-related sports varies as a function of sport classification, geographical region, and tradition or culture. It is estimated that 83 to 97 civilian firearms per 100 persons are owned in the United States, [1] and many are used for hunting purposes. In 2015, 14.8 million hunting license holders purchased permits in the United States. [3] In 2010, 1.7 million youths were hunters. [4] A survey of Colorado and Michigan youth who hunt revealed that recreational shooting begins early in life: 57% of the youth began to shoot before the age of 8 years. [5] Over 20 million Americans participated in target shooting-related activities in 2011. [6] Target shooting activities can be described as plinking (informal), sighting-in, training-related, equipment-related (ammunition, weapon), sporting clay/skeet/trap, tactical, and competitive. Geographically, the International Practical Shooting Confederation exemplifies the global popularity of dynamic target sport shooting with six worldwide geographical zones (African, Australasian, European, Pan-American, North American, and South American) and 100 national affiliates hosting shooting events at least annually. Regardless of the setting or the sport, it is the gunshot that poses the hazard to hearing.

The “BANG”

Once the trigger is pulled, a chain of events leads to the physical generation of a high-frequency, short-duration impulse waveform perceived by human ears as a single bang or gunshot (see illustration in Rasmussen et al [7]). The waveform is generated by the firing pin hitting the cartridge, detonating the primer, which then combusts the gunpowder. The gunpowder combustion produces a large volume of gas, and the resultant pressure accelerates the projectile down the barrel of the gun, where it exits the muzzle. Some projectiles travel at supersonic speeds, producing a conical shock wave commonly called a sonic boom that expands outward from the location of the projectile tip, similar to the wake produced by a motorboat in the water. Once the hot compressed gases are released, a spherical blast wave initially centered on the muzzle will be produced. Turbulent airflow around and in front of the muzzle is created as the gas is ejected forward. Outdoors, in a nonreverberant environment, the duration of the recreational gunshot is extremely brief, typically less than 10 milliseconds.

Accurate acoustic measurement of a gunshot requires specialized hardware and software that is able to capture the rapid rise time and extreme magnitude of the pressure changes from ambient to peak and back to ambient air pressure. It is necessary to utilize a small-diameter precision microphone with sufficient dynamic range and frequency response capable of capturing the wide dynamic range of the impulse. A data acquisition system incorporating a high sampling rate is also necessary to preserve the details of the impulse waveforms. High-quality impulse recording allows the detailed resolution and analysis of the impulse waveform that permits identification of the different source mechanisms and quantification of auditory risk. [7] The acoustic characteristics of the recreational firearms described in Table 1 were each measured by the authors using this type of specialized instrumentation rather than commercial or laboratory grade sound level meters.

The maximum peak sound pressure levels (SPLs) from firearms range from ~140 to 175 dB. [7] [8] [9] [10] [11] [12] [13] The majority of recreational firearms (excluding small-caliber 0.17 and 0.22 rifles and air rifles) generate between 150 and 165 dB peak SPL. The general range of peak SPLs measured at the left ear of a right-handed shooter for various categories of recreational firearms are summarized in Table 1 . [7] [8] [9] [10] [11] [12] Pistols have shorter barrel lengths than rifles and shotguns and rank high in peak SPL due in part to the closer proximity of the muzzle to the ears. Shorter barrel lengths found in both youth firearms and assault rifles also increase the SPL measured at the shooter's left ear. [11] [14] The left ear is reported due to the higher asymmetrical exposure from a rifle or shotgun gunshot and higher prevalence of hearing loss in the left ear of right-handed shooters, as addressed later in this article.

High-level exposure to impulse noise from recreational firearms also can be encountered by nonshooters, or those in close proximity to the shooter. This may be the situation for instructors, spectators, athletes, or other nearby shooters. Flamme et al measured the peak SPLs from 15 recreational firearms at the position of a bystander located 1 m to the left of the shooter in an outdoor environment. Instantaneous peak levels ranged between 149 and 167 dB and were considered to be unsafe exposures for the bystanders. [15] Athletes and spectators near officials firing starter pistols are also at an elevated risk of noise-induced hearing loss (NIHL). [10] The use of electronic starting devices for signaling the start of athletic events may minimize auditory risk.

As Kardous et al point out, there is no universally accepted standard method for measuring impulse noise. [16] Readers are cautioned to critically evaluate the peak SPLs that are measured/reported using conventional sound level meters, including those adapted for impulse noise measurements (e.g., one-quarter- or one-eighth-inch microphones, peak setting, impulse setting) due to limitations related to the microphone sensitivity, temporal constants, filter effects, voltage supply, analog-to-digital sampling rate, and output/display mode. [17] [18] Meinke et al compared rifle gunshot peak SPLs from four commercial sound level meter models marketed specially for impulse noise measurements to a gold-standard research measurement system. [18] The researchers concluded that the use of a commercial sound level meter for firearm impulse noise measurements may underestimate auditory hazard for impulse sound levels at or above ~150 dB peak SPL. Noise dosimeters are known to have similar constraints in terms of accuracy due to microphone and electronic circuitry limitations for high-level impulses from weapons. [16] Noise dosimeters and commercial sound level meters clip the peak pressure measurement when impulses exceed the dynamic range maxima (typically 150 dB or less) of the instruments and incorrectly report the clipped (underestimated) value as the peak SPL. [19]

In the past, these conventional sound level measurement limitations have likely contributed to the ceiling limit of 140 dB SPL referenced on noise thermometers used for educational purposes. Ideally, contemporary educational materials, infographics, and counseling tools should be updated to consistently reference evidence-based unweighted *peak* SPLs when communicating the auditory risk from recreational firearms to the public. A few examples of correctly referenced firearm levels in noise thermometers are provided in Fig. 1 .

Auditory Risk From Firearm Impulse Noise

Quantifying the actual risk to the auditory system based upon the acoustic characteristics of impulse noise is complex. Contemporary damage risk criteria have been categorized into three types: impulse waveform parameter-based, total energy within the impulse, and theoretical ear-based electroacoustic models of the auditory system. [20] [21] Waveform parameter-based damage risk criteria are typically quantified in terms of the peak amplitude, pressure wave, and envelope duration of the impulse. [22] Other damage risk criteria reference the energy-based, integrated A-weighted 8-hour equivalent level, [23] [24] [25] apply criteria derived from theoretical physiologically based ear models such as the Auditory Hazard Assessment Algorithm for Humans, [26] or apply fatigue modeling to predict cochlear structure damage. [27] These more complex approaches are typically utilized for research or military purposes and, once validated fully, could better inform health care providers and the public. In the meantime, the peak SPL measured at the ear level of the shooter is commonly referenced for quantifying auditory risk for clinical applications and educational interventions.

Definitive impulse noise risk limits for the human ear are also difficult to determine due to the safety considerations that limit present-day human research into this area. Consequently, animal studies utilizing the chinchilla (and other animal models) have been relied upon to explore the relationship between impulse noise exposure and hearing loss. [28] [29] [30] [31] Henderson and Hamernik determined that the critical boundary for impulse noise exposure for the chinchilla is ∼140 dB peak SPL, but noted that the risk boundary is ultimately dependent upon the actual waveform characteristics. [31] Research evidence also suggests that impulse noise is more damaging than continuous noise and that recovery is prolonged and less complete. [28] [29] [30] [31] Chan et al have modeled human recovery from temporary threshold shift measured at 2 minutes postexposure (TTS_2) using chinchilla auditory brainstem response data. [30] The recovery window for a 25 dB TTS_2 is predicted to be within 43 hours, with a longer full recovery time for a 50 dB TTS_2 extending out to ∼38 days.

Ultimately, four acoustic parameters of the noise source interact and determine the resulting hearing loss: (1) type of noise (continuous, impulse/impact, blast), (2) SPL, (3) duration and temporal pattern of the exposures (how long and how often), and (4) spectral composition. [32] More recently, there has been a growing interest in waveform kurtosis, a statistical measure of the relative peakedness or flatness of the noise distribution, which also may be useful in predicting hearing damage from impulse signals. [28] [33] [34] The acoustic characteristics of a gunshot from a recreational firearm are generally described as impulsive, peak SPL greater than 140 dB, brief duration (<10 milliseconds outdoors), and high frequency, with spectral peaks between 400 and 2,000 Hz.

There are no mandated impulse noise regulations imposed on recreational firearm shooters. The World Health Organization recommends peak SPLs not exceed 140 dB for adults and 120 dB for youth. [35] The U.S. Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health USA incorporate a peak limit of 140 dB SPL for occupational noise exposures. [36] [37] The European Union incorporates a C-weighted peak limit of 137 dB SPL in recommended guidelines for adult workers. [38] All of the rifles, pistols, and shotguns measured in Table 1 exceed these peak SPL limits for both adults and children. The majority of air rifles, with the exception of the Gamo Whisper model pellet gun and the Daisy Red Ryder Model BB gun, exceeded the 120 dB peak SPL limit for youth, but none exceeded the 140 dB peak SPL limit for adults. Without mandated noise limits, the organizations sponsoring shooting events and the individuals participating in or attending the events are responsible for hearing loss prevention.

Hearing Loss From Firearm Impulse Noise

As early as 1860, Toynbee recognized the pattern of asymmetrical high-frequency hearing loss (HFHL) in patients shooting firearms for sport. [39] He also recognized the distinction between immediate hearing loss and tinnitus following shooting and gradual onset NIHL that was attributed to repeated exposures to impulse noise over time. [40] Today, it is readily accepted that unprotected noise exposure from firearms can lead to permanent NIHL, as a result of direct mechanical damage or secondary physiological and biochemical inner ear effects from repeated gunshot exposures over time or from a limited number (including a single shot) of high-intensity exposures termed *acoustic trauma* . Tinnitus also can develop as a consequence of firearm noise exposure and should be considered an early warning sign of overexposure. [5] [41] [42]

The prevalence of bilateral high-frequency NIHL in sports shooters has been estimated by numerous epidemiologic and experimental studies over the years, comparing audiometric data from groups of individuals who engage in recreational shooting with a matched group who do not shoot for sport. [43] [44] [45] [46] In a 1966 study, sport hunters (n = 103) were found to have significantly worse hearing thresholds at 3 to 8 kHz (especially at 6 kHz) when compared with physician nonhunters (n = 21). [43] Left ear hearing thresholds were significantly poorer than right ear thresholds. Updike and Kramer found significantly poorer hearing at 2, 3, 4, and 6 kHz when comparing the hearing thresholds of 60 recreational shooters with age-matched nonshooters. [44] The greatest differences were found at 4 and 6 kHz, left ears were poorer than right ears, and older shooters had significantly greater hearing loss than younger shooters. Nondahl et al reported hearing threshold outcomes from males aged 48 to 92 years, who participated in baseline hearing tests (n = 1,538) as part of a larger Epidemiology of Hearing Loss Study. [45] An HFHL was defined as a pure tone average of hearing thresholds at 4, 6, and 8 kHz greater than 60 dB hearing loss in the worse ear, in an effort to differentiate those with greater hearing loss and account for any asymmetry between ears. A history of target shooting and hunting were each associated with marked HFHL in men after adjusting for age and other factors. Hunting increased the risk of having a severe HFHL by 7% for every 5 years the men had hunted.

The most relevant current U.S. epidemiologic hearing data are based upon a comparison of audiometric data from the recent National Health and Nutrition Examination Survey (NHANES) 2011 to 2012 cycle to the 1999 to 2004 NHANES cycle for 20- to 69-year-olds. [46] The authors report that the overall prevalence of unilateral and bilateral speech-frequency hearing loss significantly decreased from 15.9% (28 million) to 14.1% (27.7 million) after adjustment for age and sex. Firearm use (recreational, job, or military) was reported by 45.7% of the population with 32.6% shooting < 1,000 lifetime rounds and 12.9% shooting ≥ 1,000 lifetime rounds. The prevalence of both speech-frequency and high-frequency hearing impairment as related to firearm use is provided in Table 2 . The prevalence of high-frequency hearing loss (37.1%) is greater than the prevalence of speech-frequency hearing loss (17.3%) in firearm users. When considering speech-frequency hearing impairment, bilateral hearing impairment (10%) is only slightly more prevalent than unilateral impairment (7.3%). However, differences in bilateral (24.8%) versus unilateral impairment (12.3%) are much larger for high-frequency hearing impairment. Bilateral hearing impairment is also more common than unilateral impairment when considering the number of lifetime rounds fired. Left versus right ear differences (asymmetry) were not analyzed separately in that study.

The increased prevalence of bilateral (better ear) speech-frequency hearing impairment and bilateral (better ear) high-frequency hearing impairment and higher odds ratios (ORs) related to firearm use are summarized in Table 3 , including relevant adjustments for all hearing impairment risk factors (age, sex, race/ethnicity, educational level, smoking, hypertension, diabetes, occupational noise exposure, and nonoccupational noise exposure). [46] Heavy use of firearms (≥1,000 rounds fired) significantly increased the risk of speech-frequency hearing impairment in both the better and worse ears (unadjusted OR, 3.7:

95% confidence interval [CI], 1.7 to 5.7). When considering *all* of the noise exposure variables, firing 1,000 or more lifetime rounds retains a statistically significant association (OR, 1.8; 95% CI 1.1 to 3.0) and further emphasizes the public health risk that firearm use presents to the avid shooter's hearing.

Young adults or youth who shoot firearms are also at risk of NIHL. High frequency hearing loss and a notched audiometric configuration, especially at 6 kHz, is associated with recreational firearm use in 10- to 20-year-olds. [47] [48] [49] In contrast, Henderson et al (who investigated trends in noise-induced threshold shifts in youth age 12 to 19 years using audiometric data from NHANES in 1988 to 1994 and 2005 to 2006) found that the use of firearms was not associated with a significant increase of noise-induced threshold shifts (OR, 1.43; 95% CI, 0.94 to 2.17) in a multivariable model adjusted for age, gender, race/ethnicity, and poverty/income ratio. [50] Interestingly, firearm users were more likely to report using hearing protection regularly than other youth, which might account for this result.

Occupational and Firearm Noise Exposure

Clark estimated that 50% of U.S. industrial workers are exposed to gunfire noise from hunting or target shooting. [51] Several studies have considered the additional contribution of recreational firearm noise exposure to occupational hearing loss in workers with equivalent occupational noise exposure. Significantly poorer high-frequency hearing has been reported in blue collar workers, farmers, manufacturing, railway, forestry, construction, and mining workers who use firearms, compared with respective cohorts who do not shoot. [52] [53] [54] [55] [56] [57] [58] [59] [60] [61] [62] Johnson and Riffle noted that hearing loss was 9 to 16 dB poorer at 3, 4, and 6 kHz for male workers with a positive history of shooting. [53] No significant differences in hearing were evident for the small number of female shooters, and the authors attributed this to females primarily shooting small-caliber (0.22) firearms as compared with the larger-caliber firearms used by the males in the study. Forestry workers with exposure to firearm impulses had 9 dB greater hearing loss at 4 kHz and 10 dB greater hearing loss at 8 kHz than those with low exposure to shooting impulses. [58] Over 90% of farmers report firearm use, [61] and Humann found that years of hunting and target shooting were associated with HFHL in a sample of 1,568 farmers. [62] Becket et al used audiometric data to calculate binaural hearing impairment ratings in farm workers. [57] Years of hunting (but not target shooting) was associated with hearing impairment, which increased 0.16% per year of hunting. For construction workers who shoot, it is not only firearm use that puts them at risk of NIHL, but also their frequent participation in other nonoccupational noise-hazardous activities that increases their risk when compared with construction workers who do not shoot. [59]

Asymmetrical Hearing Loss in Shooters

Asymmetry (5 to 30 dB) in hearing thresholds between the ear ipsilateral to the firearm and contralateral to it may be evident in shooters (Fig. 2). The ipsilateral ear is the right ear of a right-handed shooter and, typically, the hearing loss is worse for the contralateral (left) ear. Taylor and Williams noted the left ear was 26 dB worse at 3, 4, and 6 kHz in hunters and only 4 dB worse in control subjects. [43] Chung et al noted that 13% of workers shouldered their weapon on the left shoulder and asymmetry in pure tone thresholds were significant at 2 to 8 kHz for shooters with ≥10 years shooting history. [52] Sataloff et al compared the hearing loss between ears in left- and right-handed shooters using rifles or shotguns. They noted that 60% of the left-handed shooters had more hearing loss in their right ear and 66% of the right-handed shooters had more hearing loss in the left ear. [63] Agnew postulated that the asymmetrical hearing loss is due to the nature of the placement of the firearm when shooting. [64] The shouldering of the firearm differs between right- and left-handed shooters when shooting rifles and shotguns.

A right-handed shooter will position the stock of the rifle or shotgun on the right shoulder and a left-handed shooter will position the stock on the opposite shoulder. This creates a head tilt resulting in exposure differences across ears due to the head-shadow effect. For a right-handed shooter, the head is tilted toward the right shoulder and the left ear is angled forward, closer to the muzzle blast. Fig. 3 illustrates the peak SPL differences simultaneously recorded by the authors at each ear with and without the head in place. Gunshots were generated with a 0.22 caliber Winchester Model 43 Hornet by a right-handed shooter. A difference of 9.8 dB is evident and attributed to diffraction of the impulse by the head for the left ear and shadowing by the head and shoulder for the right ear, without consideration for any potential effects of hearing protector attenuation. These measurements clearly support a difference in exposure between the two ears that may translate to asymmetrical hearing loss. However, the degree of asymmetry may vary with gun type, the use of hearing protection, and other directional and nondirectional noise exposures over time. A pistol shooter typically holds the firearm with both hands in a centered position and the head-shadow effect is minimized. There may be other factors that influence the (a)symmetry of hearing loss, including years of shooting, [63] number of rounds fired, [54] eye preference for shooting, [65] and physiological differences between ears. [58 65 66]

The Demand for Audibility

All recreational shooters, including those with hearing loss, demand audibility while engaged in their sport. Interpersonal speech communication is critical for establishing logistical plans, conveying instruction, and ensuring general safety, such as hearing a warning message or voice commands from a fellow shooter or range master. Hearing is needed to monitor the firearm assembly and function to determine if the action is fully engaged, a cartridge is loaded in the chamber, the hammer is set, a spent shell is ejected, or a safety mechanism activated. Hearing also may be used to recognize the timing of target launch and register the accuracy of a shot in terms of hearing the projectile physically impact the target. For hunters, the demand for auditory situational awareness extends to localizing the sound of wildlife (especially at a distance), monitoring the sound of their own body movements during silent approach, detecting hunting dog barks or beeper collar signals when on point, and calling to waterfowl and wildlife. Strategies to prevent NIHL and tinnitus must be considered in the context of the audibility demands of the shooter. Fortunately, the value of hearing is appreciated by most individuals experienced in shooting sports, and the motivation to protect their hearing is usually already established within the context of being physically safe and successful at their sport. It is advantageous to counsel younger or novice shooters regarding the value of their hearing as it relates to their general safety, firearm safety, and sport performance.

Hearing Protection Devices Designed for Use in Shooting Sports

Despite the recognition that firearms produce hazardous levels of sound that can damage the auditory system, 38% of adult target shooters and 95% of adult hunters report never wearing hearing protection devices (HPDs) while shooting in the past year. [45] The inconsistent pattern of HPD use in youth recreational firearm users somewhat mimics the behavior of adults. [42 67 68] The majority (62%) of youth aged 10 to 17 years reported never wearing hearing protection while hunting (16%, always) and 15% never wore HPD while target shooting (56%, always). [5] The increased use of HPDs while target shooting is likely related to the enforcement of shooting range rules and a lower reliance on the audibility of environmental sounds as compared with hunting sports. Additionally, the majority of recreational shooters are unfamiliar with alternatives to conventional hearing protectors that provide minimal attenuation for low-level sounds but provide substantial protection for high-level impulses. It is encouraging to note that youth who shoot are more likely to report using hearing protection regularly than their peers. [50]

The attenuation of hearing protectors is commonly labeled (and marketed) with values obtained using continuous noise at hearing threshold levels in a laboratory setting (e.g., noise reduction rating). When products designed for impulse noise are tested under these conditions, the noise reduction rating is negligible (<10 dB) and the consumer is left misinformed. In reality, the attenuation of an impulse sound tends to increase with the level of the impulse for traditional earplugs and earmuffs. [69] [70] [71] From a simplified perspective, auditory protection is dependent upon the proper fit of the HPD and sufficient attenuation for the peak SPL of the impulse.

Two types of hearing protectors have been developed to further address the need for situational awareness while shooting: electronic hearing protectors and small-orifice, filtered or valved passive protectors. Electronic HPDs rely upon a power supply and utilize circuitry to restore audibility for the wearer when sounds are below ~85 dB SPL and limit the long-term average output level to 82 to 85 dB SPL. These devices may include the option of amplification of low-level sounds, which may be highly advantageous for hearing-impaired sport shooters and for hunters to hear approaching game. The passive attenuation characteristics of the electronic protector (i.e., electronics turned off) will determine the attenuation for high-level impulse sounds greater than 150 dB SPL. The circuitry is too slow to respond, and the high-level impulse signal is clipped when it is processed. For peak levels less than 130 dB SPL, electronic circuitry performance may be a significant contributor to the impulse levels measured under the protector, particularly in the case of devices designed to add gain or compress high-level signals. [71] Electronic hearing protectors come in a variety of styles, including circumaural earmuffs, universal-fit insert earplugs, custom-fit earplugs, and behind-the-ear devices connected to an earplug. An electronic, level-dependent, in-the-ear style protector may preserve sound localization in the horizontal plane better than an earmuff or behind-the-ear style electronic protector. [72] [73]

The second type of protector designed for high-level impulse attenuation utilizes a small-orifice filter or a mechanical valve. At low levels of sound pressure, audibility is maintained, and at high levels the acoustic pressure flow through the orifice becomes more turbulent and provides increased acoustic resistance. [74] Flamme and Murphy caution that increased acoustic resistance does not necessarily result in adequate protection, and the ear may be exposed to 150 to 165 dB peak SPLs even when protectors are properly fit. [21] Berger and Hamery demonstrated that mechanically valved hearing protectors may provide only 10 dB of peak noise reduction through peak SPLs of 170 dB, and of greater concern, amplified peaks below ~150 dB SPL. [75] Ongoing work is underway to standardize laboratory testing and performance characteristics of hearing protectors designed for auditory protection from impulse noise across a range of impulse levels (ANSI S12.42).

Dual hearing protection (earplug worn in combination with an earmuff) provides the greatest protection. [76] Recreational shooters may find it advantageous to use a conventional earplug with electronic earmuffs. The choice of hearing protection also may vary as a function of shooting activity. It is much easier to comply with dual hearing protection use in a target-shooting range environment than when bird hunting in a heavily wooded area where earmuffs become entangled in brush. Regardless of the style of hearing protector, the fit of the protector is critical. Eyeglass temples, hats/caps, hoods that interfere with the seal reduce mean attenuation across test frequencies by 5 to 15 dB. [76] [77] It is also advisable to remind shooters that the HPD should be securely in place before shooting and that physical movement related to the force of the recoil may kick the earmuff off the ear. Wearer comfort is also an important consideration driving the choice of protector to assure adequate wear time.

It is common for shooters to recognize the need to use HPDs when shooting larger-caliber/gauge firearms and dismiss the need for protection when shooting smaller calibers, such as a 0.22 pistol/rifle. This erroneous decision making arises from poor relative loudness judgments being made across gunshots from different firearms. The high probability that a recreational shooter has a hearing loss, combined with the brief signal duration of a gunshot, will often lead the shooter to underestimate the sound level of the impulse and perceive it to be innocuous. Reliance upon subjective judgments of auditory risk should be discouraged, and hearing protection should be used for all types of recreational firearms. It may be useful to use an analogy in which the comparative sound energy emitted by a single shot from a firearm at 140 dB peak SPL is equivalent to almost a full day exposure to continuous noise at 85 A-weighted decibels integrated with a 3 dB exchange rate. Firing 1,000 rounds would then incur the equivalent of 3 years of allowable noise exposure. In other words, the number of allowable shots adds up quickly over a lifetime of sport shooting. This may serve to put the risk in perspective for the shooter and help them recognize the cumulative risk of multiple shots and stresses the importance of routine use of hearing protection. Consistent use of hearing protection by adults is also an important aspect of mentoring health and safety behaviors for young shooters.

Factors that Influence the Risk of Noise-Induced Hearing Loss

Regardless of the sport, the use of hearing protection while shooting is essential. However, there are additional strategies that can be implemented to prevent NIHL and tinnitus from firearm use (see Fig. 4).

Muzzle brakes (ports) are utilized to counter the physical effects of recoil (kickback) when a gun is discharged by redirecting the propellant gases perpendicularly relative to the barrel through slots, vents, holes, or baffles positioned at the end of the muzzle. The use of muzzle brakes should be avoided because they increase the noise hazard. Escaping gases are ejected closer to the ear and radiate more sound pressure backward toward the shooter, which increases the exposure measured at the shooter's ear. [15]

The *number of shots* fired without hearing protection increases the risk of NIHL. Small game and waterfowl hunters may be at greater risk of NIHL due to shooting hundreds of rounds per season, in comparison to large game hunters who may only fire their rifle a few times during the season. [42] Target shooters and competitive shooters also increase their risk dependent upon their choice of caliber/gauge and the number of shots fired. Shooting in groups increases the auditory hazard to the ears of the shooter, because the exposures come from both their own firearm and from other, nearby shooters. [9] Increasing the distance between shooters and minimizing the number of shots fired reduces the risk of NIHL. Shooting at ranges during off-hours may lower the number of impulse exposures from nearby shooters.

Shooting in an enclosed, reflective, reverberant environment (indoors or hunting blind) increases the hazard to hearing. [21] [78] Hunting blinds are permanent or portable structures used to camouflage the hunter within the natural environment. While hunting, shooting inside a blind may be inadvertent, or in the case of poachers, intentional to avoid visual detection. For historical reenactments or entertainment purposes, the shooting environment may be intentionally designed to replicate a scene, while neglecting the acoustic implications. Shooting from a bench or over a table also increases the peak SPL reaching the shooter's ear. [11] Design considerations and acoustical treatments for indoor shooting ranges can help minimize the auditory risk. [13] [79] [80] Recreational shooters should be encouraged to shoot outdoors and, if shooting indoors, counseled to select ranges with acoustical treatments that help minimize the risk. Spectators should be located at sufficient distances to lower the peak levels below 140 dB and below 120 dB if children are present. Technological advancements in sports filming and projection may provide spectators with close-up viewing from a distance at shooting events.

Ammunition containing less propellant decreases impulse level. Small differences in peak SPL can be measured across most kinds of ammunition for recreational firearms. [8] [11] *Subsonic or low-velocity ammunition* (velocity less than 1,120 feet per second or 341 m/s) contains a lower propellant charge and lessens the speed of the projectile, eliminating the noise source caused by the supersonic flight of the projectile breaking the sound barrier once it leaves the barrel. Firing ammunition labeled as subsonic or low-velocity less than 1,120 feet per second (341 m/s) can lower peak SPL measurements by 10 or 15 dB. [81] For hunters, the choice of ammunition is less flexible than for target shooters. The cost of ammunition may also be inversely related to the number of shots fired, with more expensive ammunition being used less often.

A *firearm suppressor* is designed to reduce the sudden release of pressure from the escaping gases (noise) by coupling a large-volume chamber to the muzzle of the firearm. Baffles within the chamber act to diffuse the energy of the blast wave propelling the projectile and reduce the sound levels of subsonic projectiles. Suppressors are often incorrectly called silencers because high-level sounds are still generated. Two recent studies have measured the peak impulse levels in suppressed and unsuppressed conditions using both subsonic and supersonic ammunitions measured at the left ear of the shooter. [14] [82] Lobarinas et al found that suppressors ($n = 14$) coupled to AR-15 rifles ($n = 15$) reduced the mean peak levels by 18 to 22 dB relative to the unsuppressed condition. [14] Murphy et al measured firearm noise with two different rifles (0.223 and 0.308 caliber) using subsonic and supersonic ammunition, with and without suppressors, and at three different microphone locations (shooter's right ear, left ear, and at the instructor's position 1 m behind the shooter). [82] Across microphone locations, peak SPLs for the subsonic ammunition ranged from 100 to 132 dB SPL in the suppressed conditions. The levels were 127 to 149 dB SPL for the unsuppressed conditions. Peak SPLs for the supersonic ammunition ranged from 120 to 137 dB in the suppressed conditions compared with 148 to 161 dB for the unsuppressed conditions. It appears that combining the use of suppressors with subsonic ammunition can further reduce the exposure, based on these preliminary studies on a limited number of firearms and suppressor combinations. The peak reduction afforded by the use of a suppressor does not always reduce the peak level below 120 to 140 dB, and marketing claims to the contrary should be considered with skepticism, especially in the context of firearms with short barrel lengths or when supersonic ammunition is fired. [14] [82] The use of hearing protection is still recommended even when using a suppressor.

Education

The diversity of firearm-related activities and recreational firearm users necessitates the creation of unique public health messaging and interventions designed and evaluated for specific audiences worldwide. Understanding the unique shooting and audibility demands of each firearm-related sport will better inform training content. Health communication science is useful as a framework for developing, implementing, and evaluating hearing loss prevention programs for firearm users. The Dangerous Decibels ® educational program has adapted its small-group classroom program to incorporate firearm-specific content in terms of acoustic trauma from a single shot, sound levels of various firearms, types of specialized hearing protectors for shooting sports, and modeling peer interactions at a shooting range (www.dangerousdecibels.org). [83]

Partnerships are needed between the hearing health community, shooting sport groups, and wildlife conservation organizations to develop and disseminate accurate information and promote organizational resources that support hearing loss prevention efforts. The shooting sportsperson depends on informed health care providers and evidence-based product information to equip them to preserve their hearing and afford long-term opportunities to enjoy their sport(s) safely. Aim to be an informed resource in your community.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

References

1. Karp A. Small arms survey 2007. Available athttp://www.smallarmssurvey.org/fileadmin/docs/A-Yearbook/2007/en/full/Small-Arms-Survey-2007-Chapter-02-EN.pdf. Accessed August 23, 2017

2. National Shooting Sports Foundation Report.Women Gun Owners Newtown, CT: NSSF; 2015

3. United States Fish & Wildlife Service (USFWS).National hunting license report 2015. Available athttps://wsfrprograms.fws.gov/subpages/licenseinfo/HuntingLicCertHistory20042015.pdf. Accessed August 23, 2017

4. Families Afield.An initiative for the future of hunting 2010. Available atwww.familiesafield.org/pdf/FamiliesAfield_Report.pdf. Accessed January 2017

5. Stewart M, Meinke D K, Snyders J K, Howerton K. Shooting habits of youth recreational firearm users. Int J Audiol. 2014;53 02:S26–S34. [PubMed: 24564690]

6. Southwick Associates.Target shooting in America report. 2011Available athttps://issuu.com/nssfpublications/docs/nssf_target_shooting_in_america_rep?e=2322682/5987375. Accessed August 23, 2017

7. Rasmussen P, Flamme G, Stewart M, Meinke D, Lankford J. Measuring recreational firearm noise. Sound & Vibration. 2009;43(08):14–18.

8. Flamme G A, Wong A, Liebe K, Lynd J. Estimates of auditory risk from outdoor impulse noise. II: Civilian firearms. Noise Health. 2009;11(45):231–242. [PubMed: 19805933]

9. Murphy W J, Flamme G A, Finan D S et al.Noise exposure profiles for small-caliber firearms from 1.5 to 6 metersPaper presented on October 22, 2012 at the 164th Acoustical Society of America Meeting, Kansas City, MO: 1–21

10. Meinke D K, Finan D S, Soendergaard J et al.Impulse noise generated by starter pistols. Int J Audiol. 2013;52 01:S9–S19. [PMCID: PMC4617326] [PubMed: 23373743]

11. Meinke D K, Murphy W J, Finan D S et al.Auditory risk estimates for youth target shooting. Int J Audiol. 2014;53 02:S16–S25. [PMCID: PMC4659434] [PubMed: 24564688]

12. Lankford J E, Meinke D K, Flamme G A et al.Auditory risk of air rifles. Int J Audiol. 2016;55 01:S51–S58. [PMCID: PMC4896309] [PubMed: 26840923]

13. Kardous C A, Murphy W J. Noise control solutions for indoor firing ranges. Noise Control Eng J. 2010;58(04):345–356.

14. Lobarinas E, Scott R, Spankovich C, Le Prell C G. Differential effects of suppressors on hazardous sound pressure levels generated by AR-15 rifles: Considerations for recreational shooters, law enforcement, and the military. Int J Audiol. 2016;55(01) 01:S59–S71. [PubMed: 26821935]

15. Flamme G A, Stewart M, Meinke D, Lankford J, Rasmussen P. Auditory risk to unprotected bystanders exposed to firearm noise. J Am Acad Audiol. 2011;22(02):93–103. [PubMed: 21463564]

16. Kardous C A, Willson R D, Murphy W J. Noise dosimeter for monitoring exposure to impulse noise. Appl Acoust. 2005;66(08):974–985.

17. Hamernik R P, Hsueh K D. Impulse noise: some definitions, physical acoustics and other considerations. J Acoust Soc Am. 1991;90(01):189–196. [PubMed: 1880288]

18. Meinke D K, Flamme G A, Murphy W J et al.Measuring gunshots with commercial sound level meters. NHCA Spectrum. 2016;33(01):26.

19. Kardous C A, Willson R D. Limitations of using dosimeters in impulse noise environments. J Occup Environ Hyg. 2004;1(07):456–462. [PubMed: 15238316]

20. Flamme G A, Liebe K, Wong A. Estimates of the auditory risk from outdoor impulse noise. I: Firecrackers. Noise Health. 2009;11(45):223–230. [PubMed: 19805932]

21. Flamme G A, Murphy W J. Brief high level soundsAmerican Industrial Hygiene Association, Falls Church, VA. In press 2018

22. MIL-STD-1474E.US Army. MIL-STD-1474E Department of Defense Design Criteria Standard—Noise Limits Washington DC: Department of Defense; 20151–117.

23. Atherley G RC, Martin A M. Equivalent-continuous noise level as a measure of injury from impact and impulse noise. Ann Occup Hyg. 1971;14(01):11–23. [PubMed: 5574682]

24. Smoorenburg G F. New York: Raven Press; 1992. Damage risk criteria for impulse noise; pp. 471–490.

25. Zagadou B, Chan P, Ho K. An interim LAeq8 criterion for impulse noise injury Mil Med 2016181(5, Suppl):51–58. [PubMed: 27168553]

26. Price G R, Kalb J T. Insights into hazard from intense impulses from a mathematical model of the ear. J Acoust Soc Am. 1991;90(01):219–227. [PubMed: 1880292]

27. Sun P, Quin J, Campbell K. Fatigue modeling via mammalian auditory system for prediction of noise induced hearing lossComp Math Methods Med2015. Available at:https://www.hindawi.com/journals/cmmm/2015/753864/. Accessed August 23, 2017 [PMCID: PMC4672119] [PubMed: 26691685]

28. Hamernik R P, Ahroon W A, Hsueh K D, Lei S F, Davis R I. Audiometric and histological differences between the effects of continuous and impulsive noise exposures J Acoust Soc Am 199393(4 Pt 1):2088–2095. [PubMed: 8473621]

29. Hamernik R P, Ahroon W A, Patterson J A., Jr Threshold recovery functions following impulse noise trauma. J Acoust Soc Am. 1988;84(03):941–950. [PubMed: 3183212]

30. Chan P, Ho K, Ryan A F. Impulse noise injury model Mil Med 2016181(5, Suppl):59–69. [PubMed: 27168554]

31. Henderson D, Hamernik R P. Impulse noise: critical review. J Acoust Soc Am. 1986;80(02):569–584. [PubMed: 3745686]

32. Humes L E, Joellenbeck L M, Durch J S. Washington DC: National Academies Press; 2006. Noise induced hearing loss.

33. Davis R I, Qiu W, Heyer N J et al.The use of the kurtosis metric in the evaluation of occupational hearing loss in workers in China: implications for hearing risk assessment. Noise Health. 2012;14(61):330–342. [PubMed: 23257587]

34. Zhao Y M, Qiu W, Zeng L et al.Application of the kurtosis statistic to the evaluation of the risk of hearing loss in workers exposed to high-level complex noise. Ear Hear. 2010;31(04):527–532. [PubMed: 20588120]

35. World Health Organization (WHO).Strategies for Prevention of Deafness and Hearing Impairment. Prevention of Noise-Induced Hearing Loss Geneva, Switzerland: World Health Organization; 1997

36. Occupational Safety and Health Administration.Occupational Noise Exposure, §29CFR 1910.95, Washington DC: U.S. Department of Labor, Occupational Safety and Health Administration Fed Reg 198348469738–9744.

37. National Institute for Occupational Safety and Health USA.Criteria for a Recommended Standard: Occupational Noise Exposure—Revised Criteria DHHS (NIOSH) Publication No. 98–126 Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 1998

38. Parliament E U. Directive 2003/10/EC of the European Parliament and of the CouncilTechnical Report 2003/10/EC, European Parliament, 2008. Am., 114:1955–1967

39. Toynbee J. Philadelphia, PA: Blanchard and Lea; 1860. The Diseases of the Ear.

40. Toynbee J. Philadelphia, PA: Blanchard and Lea; 1865. The Diseases of the Ear: Their Nature, Diagnosis and Treatment.

41. Griest S E, Bishop P M. Tinnitus as an early indicator of permanent hearing loss. A 15 year longitudinal study of noise exposed workers. AAOHN J. 1998;46(07):325–329. [PubMed: 9748912]

42. Stewart M, Borer S E, Lehman M. Shooting habits of U.S. waterfowl hunters. Noise Health. 2009;11(42):8–13. [PubMed: 19265248]

43. Taylor G D, Williams E. Acoustic trauma in the sports hunter. Laryngoscope. 1966;76(05):863–879. [PubMed: 5937909]

44. Updike C D, Kramer W L. Hearing loss in recreational shooters. Hear J. 1990;43(01):22–24.

45. Nondahl D M, Cruickshanks K J, Wiley T L, Klein R, Klein B E, Tweed T S. Recreational firearm use and hearing loss. Arch Fam Med. 2000;9(04):352–357. [PubMed: 10776364]

46. Hoffman H J, Dobie R A, Losonczy K G, Themann C L, Flamme G A. Declining prevalence of hearing loss in US adults aged 20 to 69 years. JAMA Otolaryngol Head Neck Surg. 2017;143(03):274–285. [PMCID: PMC5576493] [PubMed: 27978564]

47. Axelsson A, Lindgren F. Pop music and hearing. Ear Hear. 1981;2(02):64–69. [PubMed: 7227675]

48. Kramer M B, Wood D. Noise-induced hearing loss in rural schoolchildren. Scand Audiol. 1982;11(04):279–280. [PubMed: 7163773]

49. Holmes A, Kaplan H, Phillips R, Kemker F, Weber F, Isart F. Screening for hearing loss in adolescents. Lang Speech Hear Serv Sch. 1997;28:70–76.

50. Henderson E, Testa M A, Hartnick C. Prevalence of noise-induced hearing-threshold shifts and hearing loss among US youths. Pediatrics. 2011;127(01):e39–e46. [PubMed: 21187306]

51. Clark W W. Noise exposure from leisure activities: a review. J Acoust Soc Am. 1991;90(01):175–181. [PubMed: 1880286]

52. Chung D Y, Gannon R P, Willson G N, Mason K. Shooting, sensorineural hearing loss, and workers' compensation. J Occup Med. 1981;23(07):481–484. [PubMed: 6454768]

53. Johnson D L, Riffle C. Effects of gunfire on hearing level for selected individuals of the Inter-Industry Noise Study. J Acoust Soc Am. 1982;72(04):1311–1314. [PubMed: 7142588]

54. Prosser S, Tartari M C, Arslan E. Hearing loss in sports hunters exposed to occupational noise. Br J Audiol. 1988;22(02):85–91. [PubMed: 3390636]

55. Phaneuf R, Hétu R. An epidemiological perspective of the causes of hearing loss among industrial workers. J Otolaryngol. 1990;19(01):31–40. [PubMed: 2179575]

56. Kryter K D. Hearing loss from gun and railroad noise—relations with ISO standard 1999. J Acoust Soc Am. 1991;90(06):3180–3195. [PubMed: 1787253]

57. Beckett W S, Chamberlain D, Hallman E et al.Hearing conservation for farmers: source apportionment of occupational and environmental factors contributing to hearing loss. J Occup Environ Med. 2000;42(08):806–813. [PubMed: 10953818]

58. Pekkarinen J, Iki M, Starck J, Pyykkö I. Hearing loss risk from exposure to shooting impulses in workers exposed to occupational noise. Br J Audiol. 1993;27(03):175–182. [PubMed: 8241966]

59. Neitzel R, Seixas N, Goldman B, Daniell W. Contributions of non-occupational activities to total noise exposure of construction workers Ann Occup Hyg 2004. b;4805463–473. [PubMed: 15242844]

60. Stewart M, Konkle D F, Simpson T H. The effect of recreational gunfire noise on hearing in workers exposed to occupational noise Ear Nose Throat J 2001800132–34., 36, 38–40 [PubMed: 11209517]

61. Lankford J E, Meinke D K. Acoustic Injuries in Agriculture. In: Lessenger J E, ed., editor. New York, NY: Springer New York: Springer; 2006. pp. 484–491.

62. Humann M J. Hearing loss and task-based noise exposures among agricultural populations [PhD (Doctor of Philosophy) thesis]. University of Iowa, 2011. Available at:http://ir.uiowa.edu/cgi/viewcontent.cgi?article=2371&context=etd. Accessed August 23, 2017

63. Sataloff J, Hawkshaw M J, Sataloff R T. "Gun-shooting hearing loss": a pilot study. Ear Nose Throat J. 2010;89(01):E15–E19. [PubMed: 20155683]

64. Agnew J. Gunshots and hearing. Hear Instr. 1987;38:10–12.

65. Job A, Grateau P, Picard J. Intrinsic differences in hearing performances between ears revealed by the asymmetrical shooting posture in the army Hear Res 1998122(1–2):119–124. [PubMed: 9714580]

66. Berg R L, Pickett W, Linneman J G, Wood D J, Marlenga B. Asymmetry in noise-induced hearing loss: evaluation of two competing theories. Noise Health. 2014;16(69):102–107. [PubMed: 24804714]

67. Stewart M, Foley L, Lehman M E, Gerlach A. Shooting habits of recreational firearm users. Aud Today. 2011;23:38–52.

68. Nondahl D M, Cruickshanks K J, Dalton D S et al.The use of hearing protection devices by older adults during recreational noise exposure. Noise Health. 2006;8(33):147–153. [PubMed: 17851219]

69. Murphy W J, Flamme G A, Meinke D K et al.Measurement of impulse peak insertion loss for four hearing protection devices in field conditions. Int J Audiol. 2012;51 01:S31–S42. [PMCID: PMC4677999] [PubMed: 22176308]

70. Khan A, Fackler C J, Murphy W J. NIOSH In-Depth Survey Report: Comparison of Two Acoustic Test Fixtures for Measurement of Impulse Peak Insertion Loss (No. 350–13a)NIOSH EPHB Report No 312–11a.Cincinnati, OH: DHHS-CDC-NIOSH; 20131–40.

71. Murphy W J, Fackler C J, Shaw P et al.Comparison of the performances of three acoustic test fixtures for impulse peak insertion loss measurements at an outdoor firing range. NIOSH Report number EPHB 350–14aNational Institute for Occupational Safety and Health,Cincinnati, OH: DHHS-CDC-NIOSH; 20141–45.

72. Borg E, Bergkvist C, Bagger-Sjöbäck D. Effect on directional hearing in hunters using amplifying (level dependent) hearing protectors. Otol Neurotol. 2008;29(05):579–585. [PubMed: 18520633]

73. Talcott K A, Casali J G, Keady J P, Killion M C. Azimuthal auditory localization of gunshots in a realistic field environment: effects of open-ear versus hearing protection-enhancement devices (HPEDs), military vehicle noise, and hearing impairment. Int J Audiol. 2012;51 01:S20–S30. [PubMed: 22264060]

74. Allen C H, Berger E H. Development of a unique passive hearing protector with level-dependent and flat attenuation characteristics. Noise Control Eng J. 1990;34:99–105.

75. Berger E H, Hamery P. Level dependency of various passive earplug designs2008 J Acoust Soc Am 123(5), Pt. 2:3528-3758. Available at:http://asa.scitation.org/toc/pma/4/1?expanded=4. Accessed September 7, 2017

76. Murphy W J, Tubbs R L. Assessment of noise exposure for indoor and outdoor firing ranges. J Occup Environ Hyg. 2007;4(09):688–697. [PubMed: 17654224]

77. Wells L, Berger E H, Keiper R. Attenuation characteristics of fit-compromised earmuffs and various nonstandard hearing protectors. Proc Meet Acoust. 2013;19:1–8.

78. Stewart M, Flamme G A, Meinke D K et al.Firearm noise in a hunting blind NHCA Spectrum 201128(Suppl II):47

79. Kardous C A, Willson R D, Hayden C S, Szlapa P, Murphy W J, Reeves E R. Noise exposure assessment and abatement strategies at an indoor firing range. Appl Occup Environ Hyg. 2003;18(08):629–636. [PubMed: 12851012]

80. Murphy W J, Zechmann E L, Kardous C A, Xiang N. Noise mitigation at the combat arms training facility, Wright Patterson Air Force Base, Dayton, OH. J Acoust Soc. 2012;132(03):2084.

81. Stewart M, Flamme G A, Murphy W J et al.Effects of firearm suppressors on auditory risk NHCA Spectrum 201532(Suppl I):39

82. Murphy W J, Stewart M, Flamme G A, Tasko S M, Lankford J E, Meinke D K. The reduction of gunshot noise and auditory risk through the use of firearm suppressors. J Acoust Soc Am. 2016;139(04):1984. [PubMed: 29299940]

83. Wise S, Meinke D K, Griest S, Finan D S, Weber J E. Dangerous Decibels®: Program effectiveness for youth recreational firearm usersPoster presented at: AudiologyNOW! annual conference of the American Academy of Audiology; April 2016. Available at:http://asa.scitation.org/doi/abs/10.1121/1.4799992. Accessed September 7, 2017

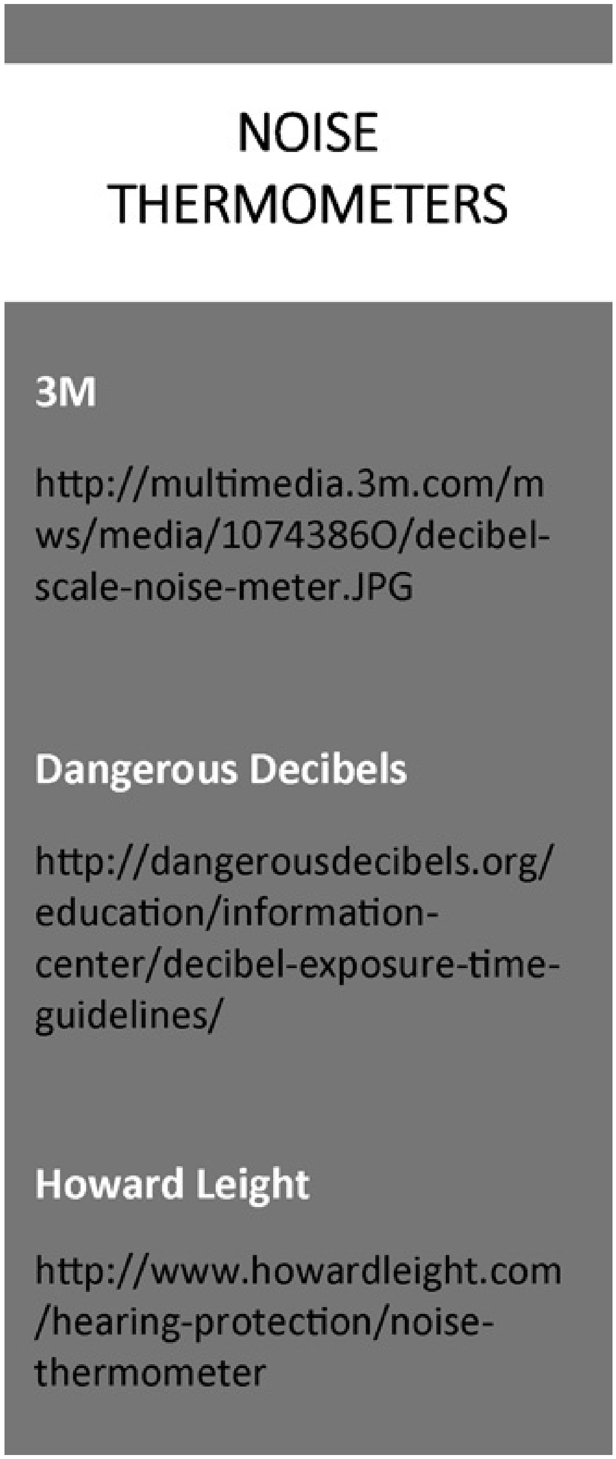
Figures and Tables

Table 1

Rank-Ordered Range of Mean Unweighted Peak Sound Pressure Levels for Recreational Firearms Measured at the Left Ear of a Right-Handed Shooter [7] [8] [9] [10] [11] [12]

Recreational Firearm Type	Peak Sound Pressure Level (dB)
Rifles (higher caliber than 0.22)	~159–174
Pistols (higher caliber than 0.22)	~148–171
Shotguns	~152–170
Starter pistols (blanks)	~148–165
Pistols (0.22 caliber)	~155–158
Rifles (0.17 and 0.22 caliber)	~140–144
Air rifles	~117–134

Figure 1



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Examples of accurate noise thermometers to use for educational purposes.

Table 2

Prevalence of Hearing Impairment Related to Firearm Use, U.S. Adults Age 20–69 years, NHANES, 2011–2012*

Firearms, Including Use for Recreation, Job, or Military (NHANES 2011–2012), U.S. Adults Age 20–69 Y	Prevalence (%)	Speech-Frequency Hearing Impairment,* % (95% CI)		
		Overall †	Unilateral ‡	Bilateral §
Not used	54.3	11.4 (9.1–14.2)	6.0 (4.5–8.0)	5.4 (4.3–6.8)
Yes used	45.7	17.3 (13.6–21.9)	7.3 (5.7–9.5)	10.0 (7.3–13.6)
<1,000 lifetime rounds fired	32.6	14.0 (10.6–18.2)	6.0 (4.2–8.4)	8.0 (5.8–10.9)
≥1,000 lifetime rounds fired	12.9	26.0 (19.7–33.4)	10.8 (8.4–13.7)	15.2 (9.4–23.6)
		High-Frequency Hearing Impairment, ‖ % (95% CI)		
Not used	54.3	25.9 (23.5–28.6)	11.6 (10.1–13.2)	14.4 (12.7–16.3)
Yes used	45.7	37.1 (31.9–42.6)	12.3 (9.4–15.9)	24.8 (20.6–29.5)
<1,000 lifetime rounds fired	32.6	32.2 (26.8–38.2)	10.2 (6.3–15.9)	22.1 (17.6–27.4)
≥1,000 lifetime rounds fired	12.9	49.7 (40.2–59.2)	18.0 (13.1–24.2)	31.7 (22.5–42.6)

CI, confidence interval; NHANES, National Health and Nutrition Examination Survey.

Note: Adapted from Hoffman et al. [46]

*Defined as pure tone average of thresholds at 0.5, 1, 2, and 4 kHz greater than 25 dB hearing loss.

†Refers to the sums of unilateral and bilateral hearing impairment, which means hearing loss in one or both ears.
‡Refers to the pure tone average in only one ear exceeds 25 dB hearing loss.
§Refers to the pure tone average in both ears exceed 25 dB hearing loss.
‖Defined as pure tone average of thresholds at 3, 4, and 6 kHz greater than 25 dB hearing loss.

Table 3

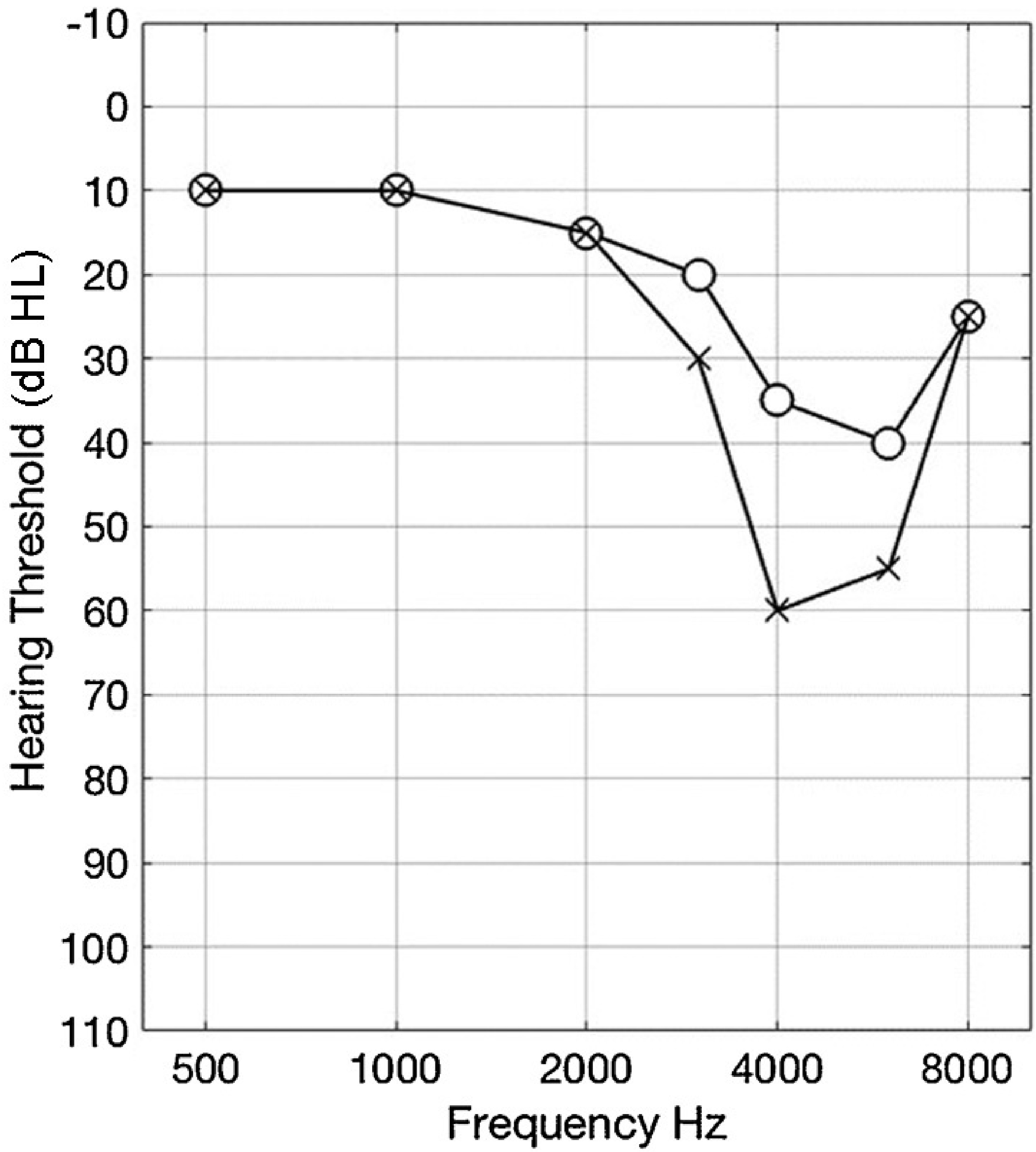
Prevalence of Bilateral (Better Ear) Hearing Impairment Related to Firearm Use, US Adults Aged 20–69 years, NHANES, 2011–2012*

Hearing Impairment	Firearms, Including Use for Recreation, Job, or Military (NHANES 2011–2012), U.S. Adults Age 20–69 Y	Prevalence, % (95% CI)	Odds Ratio (95% CI)		
			Unadjusted	Adjusted for Age and Sex	Adjusted for All Variables
Bilateral (better ear) speech-frequency impairment	None	5.4 (4.3–6.8)	1 [Reference]	1 [Reference]	1 [Reference]
	<1,000 lifetime rounds fired	8.0 (5.8–10.9)	1.5 (1.1–2.1)	1.4 (0.9–2.1)	1.4 (0.8–2.2)
	≥1,000 lifetime rounds fired	15.2 (9.4–23.6)	3.1 (1.7–5.7)	2.4(1.4–4.2)	1.8 (1.1–3.0)
Bilateral (better ear) high-frequency impairment	None	14.4 (12.7–16.3)	1 [Reference]	1 [Reference]	1 [Reference]
	<1,000 lifetime rounds fired	22.1 (17.6–27.4)	1.7 (1.3–2.2)	1.4 (0.9–2.1)	1.2 (0.9–1.9)
	≥1,000 lifetime rounds fired	31.7 (22.5–42.6)	2.8 (1.6–4.7)	1.5 (1.0–2.5)	1.3 (0.7–2.3)

CI, confidence interval; NHANES, National Health and Nutrition Examination Survey.

*Adapted from Hoffman et al. [46]

Figure 2



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Example of an asymmetrical noise-induced hearing loss (NIHL) for a 50-year-old Caucasian man who shoots recreational firearms.

Figure 3

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Illustration of head-shadow effect contrasting sound pressure levels measured for each ear for a right-handed rifle or shotgun shooter.

Figure 4

STRATEGIES TO PREVENT HEARING LOSS WHEN SHOOTING RECREATIONAL FIREARMS

- Always wear well-fit earplugs and/or earmuffs when shooting or when positioned near others who are shooting*
- Avoid the use of muzzle brakes (ports)
- Reduce the number of shots fired
- Shoot smaller caliber/gauge firearms when possible
- Shoot firearms with longer barrel lengths when possible
- Avoid shooting in groups, and if necessary, increase distance between shooters
- Avoid firing simultaneously with other nearby shooters
- Shoot outdoors or in a sound-treated indoor environment
- Avoid shooting over hard reflective surfaces such as benches or tabletops
- Shoot sub-sonic or low-velocity (<1120 fps) ammunition when feasible
- Utilize a suppressor

*The use of hearing protection is always warranted even when implementing the other listed strategies.

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Strategies for protecting hearing.