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# Auditory Risk of Air Rifles

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## Abstract

**Objective—**To characterize the impulse noise exposure and auditory risk for air rifle users for both youth and adults.

**Design—**Acoustic characteristics were examined and the auditory risk estimates were evaluated using contemporary damage-risk criteria for unprotected adult listeners and the 120-dB peak limit and $L_{Aeq75}$ exposure limit suggested by the World Health Organization (1999) for children.

**Study sample—**Impulses were generated by 9 pellet air rifles and 1 BB air rifle.

**Results—**None of the air rifles generated peak levels that exceeded the 140 dB peak limit for adults and 8 (80%) exceeded the 120 dB peak SPL limit for youth. In general, for both adults and youth there is minimal auditory risk when shooting less than 100 unprotected shots with pellet air rifles. Air rifles with suppressors were less hazardous than those without suppressors and the pellet air rifles with higher velocities were generally more hazardous than those with lower velocities.

**Conclusion—**To minimize auditory risk, youth should utilize air rifles with an integrated suppressor and lower velocity ratings. Air rifle shooters are advised to wear hearing protection whenever engaging in shooting activities in order to gain self-efficacy and model appropriate hearing health behaviors necessary for recreational firearm use.

### Keywords

Air rifles; air guns; recreational shooting; noise-induced hearing loss; auditory risk; impulse noise; youth health risk

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## Introduction

Air rifles are routinely used by both adults and youth. Individuals may use them to hunt, control pests or compete in formal shooting events or as an informal recreational activity. Target shooting at miscellaneous objects (tin cans, paper plates or cups etc.) is a common pastime, especially in rural communities or as a means of improving shooting skills. Three-position competitive air rifle sports are organized by many youth organizations including 4-H, Boy Scouts of America and wildlife conservation groups. High school, collegiate and military Junior Reserve Officer's Training Corp (JROTC) sporting competitions are also held on the local, national and international levels each year. Internationally, air guns are used for many of the same purposes although the legal restrictions and rules differ by country and jurisdiction.

In the US, youth often first learn to shoot using a BB rifle or pellet rifle (air rifles). Most hunters in the US know the Red Ryder Daisy BB rifle and many still have their original "BB guns" buried in a closet or storage area in their home. Or, they may have passed them on to their children or grandchildren. Most have certainly been warned of the potential to "shoot your eye out" however few, if any, have ever considered the possibility of sustaining a noise-induced hearing loss from a BB/pellet gun or the relevancy of the early hearing safety behaviors that are established at the time youth learn to shoot air rifles (Figure 1). Jarvis and Stark (2005) emphasized the crucial role that parents and teachers have in developing and reinforcing positive health behaviors in children especially since these adults are their primary sources of health and safety information.

One of the first known air guns dates back to 1580. These early air guns were used initially for hunting but did find a use in the military during the 18th century. The Lewis and Clark Expedition in the US in 1804 reportedly had an air rifle in .46 caliber which could supposedly launch round balls at a lethal rate of 22 per minute through a rifled barrel before reloading balls and air pressure (NRA, 1991).

With the invention of the BB gun in 1888 called the "Daisy," a low-cost air rifle took a major place in air rifle history. The "Daisy" BB gun continues to be an initial entry-level training and shooting rifle for many youngsters and occasionally the military (Hough, 1976; Murfin, 2011). The International Shooting Sports Foundation held the first World Championship for air pistols in 1966 and the first air rifle championship in 1970. The first Olympic 10-meter air rifle competitions began in 1984.

In the last 30 years, air guns have become increasingly popular not only with youngsters, but with adults due to their low cost, less restrictive access, and recreational enjoyment in both informal and competitive shooting events. Nguyen et al. (2002) report an estimated 3.2 million BB/pellet guns are sold in the US each year.

Air guns, which can be pistols or rifles, utilize compressed air or liquefied gas ($CO_2$) to propel a projectile (BB, pellet or bullet) from the barrel of a gun. In the case of some BB rifles, a mechanical spring piston may be utilized to launch the projectile (BB) rather than compressed air or liquefied $CO_2$. The bore of the air rifle barrel might be either smooth or rifled. However, firearms (pistols, shotguns and rifles) may look similar to air rifles but differ by propelling a projectile(s)/bullet from the barrel by igniting rifle powder for a fast controlled explosion. The use of air rifles in the military and in hunting waned due to the continued development and refinement of the firearm producing higher projectile velocities, flatter trajectories and great ranges. Projectile velocities from some air rifles may exceed the speed of sound in air (~1100 feet per second). Damore et al (2000) report that 80% of air rifles have velocities that exceed 350 fps. Air rifles are capable of producing muzzle velocities similar to small caliber (.22) powder rifles shooting rimfire target or sub-sonic bullets. With the higher air gun velocities comes the potential for higher noise levels which prompted the need to measure and assess auditory risk in this study.

The risk of BB and pellet guns causing lethal and non-lethal penetrating injuries to the abdomen, chest, eye and head are well documented in the literature (McGwinn, 2006; Nyguen et al, 2002; Shuttleworth and Galloway, 2001). Children and adolescents account for 80% of all non-fatal BB/pellet gun related injuries in US hospital emergency departments (CDC, 1995). Air gun velocities in excess of 331 fps are known to perforate skin (DiMaio et al., 1982). Currently, there appears to be an absence of epidemiological reports related to acoustic trauma or noise-induced hearing loss from air guns. Harada et al. (2008) does report one subject presenting with acute acoustic trauma from an air gun in a group of 20 men (aged 18–48 years) who were members of the Japanese Self-Defense Force.

One of the most common approaches to determining the potential for noise-induced hearing loss (NIHL) from rifles is to measure the instantaneous peak sound pressure level (dB SPL). Numerous agencies or organizations have suggested or recommended that levels arriving at the adult unprotected ear should not exceed 140 dB SPL for high-level impulse sounds. These groups include: OSHA (1983), NIOSH (1998) and DOD (MIL-STD-1474E). Although these criteria were established for adults, the World Health Organization (WHO) in 1999 recommended that for children, the impulse noise level should not exceed 120 dB peak SPL.

Flamme et al. (2009a) reviewed the evidence that peak SPL values do not fully represent the potential damage to the auditory system. The auditory risk of noise exposure to civilian firearms (Flamme et al, 2009b), starter pistols (Meinke et al., 2013), and youth firearms (Meinke et al., 2014) have been described using adult auditory damage risk criteria (DRC) such as maximum permissible exposures (MPE) using $L_{Aeq8}$ and the Auditory Hazard Assessment Algorithm for Humans (AHAAH) (Price & Kalb 1991; Price, 2007; Fedele et al., 2013). Strong correlations have been shown between the outcomes from these DRCs (Flamme et al., 2009b). We included both DRCs in the current study to determine if those results extend to impulses from guns that do not use chemical combustion. The US Environmental Protection Agency (EPA) (1973) and the WHO (1999) recommend that noise exposure should not exceed a 70-dBA equivalent continuous level ($L_{Aeq}$) averaged over a 24 hour period, which is approximately equal to 75 dB $L_{Aeq}$ normalized over an 8-hour period for adults. There are no auditory damage risk criteria developed specifically for children.

## Objective

This study was conducted to provide information about the noise levels from nine air rifles and a BB rifle relative to the possible auditory risks for persons using these rifles.

## Methods

### Design

The research is a descriptive study designed to investigate the auditory risk for air rifle shooters. Sound level measurements were obtained at three locations: at the air rifle muzzle and at both the right ear and left ears of the air rifle user. These locations afford a comparison between air rifles at the muzzle with regard to maximum peak sound pressures at the ear, as well as to provide a comparison of the left versus right ear potential auditory hazards.

### Air Rifles and Pellets

Impulses were evaluated from nine air rifles along with a Daisy BB rifle (Table 1). The air rifles were .177 caliber and ranged from new to more than 20 years of age. All of the pellet air rifles used a single-stoke spring-piston or a gas-spring charging mechanism. The Daisy BB air rifle used a spring-air charging mechanism. Air rifles were selected as a convenience sample to represent common commercially available air rifles that were generally representative of a range of velocities. In addition, the Daisy BB rifle was assessed due to its widespread use and familiarity by the general US public. Three air rifles were designed with an integrated sound suppressor (often called a silencer) in the barrel and identified in Table 1. Two different projectiles were shot from each compressed air rifle, a lead diabolo pellet (Gamo Hunter Impact) and an alloy diabolo pellet (Gamo Raptor PBA Supersonic Power). Impulse noise generated by the Daisy BB rifle was assessed using Daisy zinc-plated premium 0.177 inch (4.5 mm) round BBs as the projectile.

**Instrumentation—**Impulse noise recordings were made outdoors for each of the air rifles and pellet conditions using calibrated ½-inch pre-polarized pressure microphones (G.R.A.S. Type 40AG or AO) at the three locations. The microphones were connected to a pre-amplifier (G.R.A.S. Type 26AC or 25 CB) capable of carrying the large signals without overload. A constant voltage power module (G.R.A.S. Type 12AA) with adjustable gain and adequate dynamic range provided power to the microphones. Data were sampled at 200-kHz rate with National Instruments PXI-4462 modules at a 24-bit depth. The data were saved in text files for processing and analysis in MATLAB. The microphones were placed at a grazing incidence to the sound source and 1.63 meters above the ground level. Calibration was completed prior to and after all measurements.

**Experimental Procedure—**Five shots were fired on a horizontal plane for each of the two types of pellets for each air rifle. Firing was done by an experienced right-handed adult shooter from the standing position. The barrel of the air rifle was supported by a tripod and the muzzle positioned at a height of 1.63 meters. Sound level measurements were obtained at three microphone locations in the area surrounding the shooter (Figure 2). These included a muzzle microphone, a right ear microphone and a left ear microphone, each at a height of 1.63 meters. The muzzle microphone was positioned 40.6 cm to the left of the muzzle of the rifle. The right and left ear microphones were positioned at a distance of 22.9 cm from the center of the air rifle barrel line. Air rifle barrel lengths varied and the distances between the muzzle and the ear level microphones are also provided in Table 1. Each microphone was calibrated before and after the experimental measurement session.

**Analysis—**Post-processing of the impulse text data was accomplished with National Instruments DIAdem software, and subsequently transferred to MATLAB for scaling into Pascal (Pa) units using software routines originally developed in the NIOSH Taft Laboratories (Zechmann, 2012). Mean values were calculated for the five shots fired under each measurement condition. The current study included three acoustic outcome variables (peak SPL, $L_{Aeq8}$ and $L_{Aeq75}$) and two outcome variables indicating the risk of auditory damage; maximum permissible exposures (MPEs) based upon an unprotected $L_{Aeq8}$ of 85 dBA (DTAT, 1983) and MPEs calculated by the Auditory Hazard Assessment Algorithm for Humans (AHAAH) using a threshold of 500 Auditory Hazard Units (AHUs) for the unwarned ear (Price, 2007). The relative auditory risk is quantified using the EPA/WHO 75 dB $L_{Aeq8}$ due to the common use of air rifles by youth and to provide comparison to the most conservative risk criteria for adults. Associations between outcome variables and rifle features (e.g., muzzle velocity, length), loaded projectile, and microphone location were assessed using multilevel regression models. Velocity values were converted from feet per second to meters per second, and lengths were converted to meters for the inferential analyses. Regression models were developed via likelihood ratio tests. Reduced regression models were adopted when the decline in model fit was small relative to the reduction in degrees of freedom (i.e., a chi-square difference test with a $p < 0.05$).

## Results

### Peak Sound Pressure Level

Peak sound pressure levels averaged across the five shots at each microphone location for both ammunition loads are represented in Table 2. Peak level values were essentially equivalent for the left and right ears (≤ 1.1 dB difference). At the left ear microphone location, all of the pellet air guns had average peak levels between 117–134 dB SPL. The Gamo Varmint produced the highest peak level (133.5 dB). All but one of the nine pellet air guns exceeded the 120 dB peak level of the WHO criterion for youth. None of the pellet guns exceeded the 140 dB peak limit. Six (67%) of the air guns shooting pellets had higher peak levels (1.1 dB) for alloy pellets than with lead pellets. Minimal differences (≤ 1.4 dB) were observed when comparing the right versus left ear microphone measurements. Peak sound pressure level differences at the muzzle averaged 9.2 dB (lead) to 10.2 dB (alloy) higher than the left ear values. The Daisy BB gun generated one of the lowest peak levels for the left ear at 117.3 dB SPL shooting BBs.

Figure 3 provides a boxplot illustration of the relative range of left ear peak values obtained and referenced to the 120 dB WHO limit for youth and the 140 dB OSHA limits for adults.

**$L_{Aeq8}$—**The relative ranges for $L_{Aeq8}$ values for the left ear microphone are illustrated in Figure 4. The $L_{Aeq8}$ mean values ranged from 40.8 to 51.8 dB for lead pellets and 42.1 to 51.7 dB for alloy pellets. The Gamo Whisper exhibited the lowest $L_{Aeq8}$ for pellet air guns using lead, while the Red Ryder BB gun was 40.1 dB. The highest mean $L_{Aeq8}$ was measured with the Gamo Varmint Hunter air gun shooting lead pellets. Left ear mean $L_{Aeq8}$ values are below the 85 dB $L_{Aeq8}$ occupational exposure criterion recommended by NIOSH/ ACGIH.

### Auditory Risk Estimates

Figure 5 represents the relative auditory risk quantified for the EPA/WHO 75 dB $L_{Aeq8}$ (Panel A) criteria and auditory risk results computed via AHAAH (Panel B) for the left ear microphone. Auditory risk estimates were converted into maximum permissible exposure (MPE) values for an unprotected listener to facilitate comparison. The Gamo Whisper Fusion and the Gamo Varmint Hunter have the lowest permissible MPE (214 to 481) and ARU (39.5 to 44.8). The Gamo Whisper pellet air guns permit the greatest number of MPE (2,659 for lead) and ARU (402 for alloy). The Daisy BB is the least hazardous in terms of allowable exposures with a mean MPE of 3,083 and ARU of 1996.

The correlations between the logarithms of MPE values from the $L_{Aeq8}$ and AHAAH damage-risk criteria were generally high (Figure 6). The correlation was 0.93 (95 % CI [0.90 to 0.96]) at the muzzle microphone location, 0.91 (95 % CI [0.86 to 0.94]) at the left ear microphone location, and 0.91 (95 % CI [0.87 to 0.94]) at the shooter's right ear microphone location. The magnitudes of these correlations were not substantially altered when observations from the Red Ryder were excluded (0.90, 0.90, and 0.94), for the muzzle, left ear, and right ear microphone locations, respectively.

### Correlates of Air Gun Sound Emissions

As mentioned previously, associations between outcome variables (peak SPL, $L_{Aeq8}$, MPE and ARU) and gun features (e.g., muzzle velocity, distance, and suppressor), loaded projectile, and microphone location were assessed using multilevel regression models. The results of these analyses were generally similar across outcome variables. All multilevel regression models were significant (Wald Chi-square with 7 degrees of freedom $\chi^2_7 > 100$; $p < 0.00005$), and *post hoc* comparisons (Bonferroni correction) revealed that there was no consistent difference between lead and alloy projectiles for the air guns used in this study. Air guns that had an integrated suppressor tended to produce lower levels, and consequently lower levels of risk and greater numbers of permissible exposures, when other factors were constant. The magnitude of the suppressor effect varied with the outcome variable, wherein the suppressor could be expected to reduce the peak SPL by 5.6 dB (95 % CI 4.5 to 6.8 dB) and the $L_{Aeq8}$ values were reduced by approximately 2.7 dB (95 % CI 1.9 to 3.5 dB). Reductions to damage-risk criteria were sufficient to increase the expected MPE values by a factor of 1.84 (95 % CI 1.76 to 1.94) and 1.44 (95 % CI 1.34 to 1.54) percent for $L_{Aeq8}$ and AHAAH, respectively.

A significant interaction was noted between muzzle distance to the ear (i.e. barrel length) and projectile velocity. Air guns with shorter barrels and low projectile velocities produced no greater sound levels or lower MPEs than guns with longer barrels. However, the sound levels and MPEs increased more rapidly with increases in projectile velocity for guns that had shorter distances to the ear. This relationship was observed for all outcome variables, with the exception that the MPE estimates based on the $L_{Aeq8}$ metric tended to be greater (i.e., indicating less risk) for the air guns with shorter muzzle to ear distances and lower velocities, but this risk increased with projectile velocity more rapidly for shorter guns, and at the highest velocities, the shorter guns could be expected to produce the lowest MPE values. Shorter guns accelerating pellets to higher velocities can be expected to produce the greatest hazard.

A significant effect of microphone location was observed for all but the $L_{Aeq8}$ outcome variable. This effect indicated that the level near the muzzle was greater than at the shooter's left or right ear, but the levels at the shooter's ears did not differ between the right and left.

# DISCUSSION

## Risk of Hearing Loss

For this study, the preponderance (8 of 9) of the pellet rifles exceeded the WHO limit of 120 dB peak SPL and suggests a potential auditory hazard to the hearing of those who fire them. The Daisy BB rifle presented the lowest risk of hearing loss. When considering the auditory risk estimates, MPEs varied substantially across air rifles and between the EPA/WHO 75 dB $L_{Aeq8}$ criteria and auditory risk results computed via AHAAH. The low number of unprotected MPEs via the AHAAH damage-risk criterion for the Gamo Varmint Hunter and the Gamo Whisper Fusion are well below the 100 shots found in a typical box of pellets and shot during target practice, and consequently, hearing protection is especially warranted when shooting these air rifles.

The high correlations observed across MPE values returned by the damage-risk criteria are consistent with prior observations with guns and other impulsive sources that rely on chemical combustion (Flamme et al., 2009b). Although there could be small differences in rank-ordering of risk across the $L_{Aeq8}$ and unwarned AHAAH criteria, the data from this study are consistent with prior findings that the principal difference between the criteria is more a matter of scaling than a fundamental difference in the information returned across methods.

## Air Rifle and Ammunition Load Considerations

In general, the air rifle (Gamo Varmint Hunter) with the highest peak SPL (133.5 dB) is approximately 6 dB lower (139.6 dB) than the .22 caliber Remington 514 powdered youth gun measured at left ear level in Meinke et al (2014). The outcomes from this study suggest that air rifles with lower velocities and those with an integrated suppressor pose less auditory risk. When the muzzle of the air rifle is at a greater distance from the ear of the shooter, the peak SPL is reduced. Although air pistols were not evaluated in this study, it might be expected that the auditory hazard may be increased due to the closer proximity of the muzzle to the ear in these air guns; similar to the increased risk noted for powdered firearms (Meinke et al., 2013). The risk of auditory damage is similar regardless of whether lead or alloy pellets are shot and therefore other considerations (environmental, cost, etc.) may drive the purchase decisions with regard to ammunition choice.

## Air Rifle Safety

Another concern when youth are learning to shoot a rifle is the information and training received regarding their personal safety and the safety of all those in the range of the projectile of the rifle. There are numerous rules that are taught (“Air Rifles,” 1991): “Always keep the rifle pointed in a safe direction,” “Always keep your finger off the trigger until you are ready to shoot,” ”Always keep the rifle unloaded until ready to use,” etc. The recommendation to use eye protection is standard, however the recommendations for hearing protection use varies from source to source. The National Rifle Association (2006) provides the following safety guidance for air rifle shooters, range personnel and spectators;

> Hearing protectors should always be worn. Although air rifles have a considerably reduced amount of noise pressure and pulse than do firearms, *hearing protectors should be worn at all times* when on the range or on the firing line to ensure that no hearing damage occurs. Hearing protection also enhances concentration on the line by reducing distracting noises during shooting. (p.5, italics added).

Section 6.2.5 of the National Collegiate Athletic Association 2014–15 NCAA Rifle Rules Modifications Supplement No. 3 also requires the use of hearing protection at small bore and air rifle competitions;

> All athletes, range officials and other persons in the immediate vicinity of the 25m, 50m and 300m firing lines and all shotgun ranges *are urged to wear ear plugs, ear muffs, or similar ear protection*. Notices must be prominently displayed and hearing protection must be available for all persons in the range areas. *Hearing protection incorporating any type of receiving devices are not permitted for athletes*. (p. 6, italics added).

These rules are in contrast to the “A Junior Shooter’s Guide to Air Rifle Safety” (Anderson, 2012) booklet, published by the Civilian Marksmanship Program and endorsed by National Three-Position Air Rifle council comprised of the following organizations: The American Legion, Boy Scouts of America, Civilian Marksmanship Program, Daisy/U. S. Jaycees Shooter Education Program, National 4-H Shooting Sports, The U. S. Army Marksmanship Unit, USA Shooting and the Army, Marine Corps, Navy and Air Force JROTC Commands which does not require hearing protection for air rifles and specifically states that there is no risk of hearing loss.

> Some shooters *elect to wear hearing protection (ear plugs or ear muffs)* while shooting air rifles, although this is normally done by individuals who wish to reduce the effects of noise in the range to improve their ability to concentrate. Air rifles do not generate enough sound to cause hearing loss. (p. 17, italics added)

Notably, the three-position air rifle sport competitions only permit air rifles with 600 fps velocity or less and the current study did not evaluate air rifles with velocities between 350 and 600 fps.

### Implications for Prevention of NIHL

The US Institute of Medicine (2001) recommends that concurrent interventions at multiple levels (individual, family, community, and society) should be encouraged to promote healthy behaviors. Based on the findings of this study, all air rifle shooters should use hearing protection to prevent unnecessary impulse noise exposure for the purpose of conserving hearing. Since safety education is designed to establish safe behavioral habits throughout life, all youth should use HPDs while shooting air rifles and establish positive hearing health behaviors as they mature into shooting powdered firearms. Electronic level-dependent HPDs are strongly recommended for youth and adult mentors. These HPDs if appropriately worn should provide protection from the potential hazard of NIHL from rifle noise and also provide an important communication system between the youth and the parent/supervisor/trainer. Demore et al. (2000) notes that parents of children who shoot BB or pellet air rifles misperceive the potential for injury, especially if used in an unsafe manner. Therefore, they advise health professionals (clinicians) to educate parents about the potential for injury from non-powdered guns. This study further suggests that health professionals and parents should also receive information regarding the potential risk of noise-induced hearing loss and the need to utilize hearing protection by those who shoot air rifles. It is important that air rifle manufacturers routinely advise the use of hearing protection as a safety recommendation for their products. Organizations hosting air rifle shooting events will also need to be appraised of the auditory hazard and that hearing protection be mandated for all air rifle shooters. The risk to spectators and instructors was not directly investigated in this study. It is possible that risk of hearing loss extends to bystanders in close proximity to the air rifle when considering the findings of Flamme et al. (2011).

### Measurement Techniques for Air Rifle Impulses

The magnitude of exposure asymmetry in this study was small, but it is important to recognize that estimates of head shadow differences are related to the locations of the microphones and the head. Under field conditions with a person holding and firing the gun, shooter movements associated with aiming and firing the gun require placement of microphone further from the head than would be required to obtain maximum estimates of asymmetry. The orientation of the head with respect to an acoustic source (i.e. the impulse from the muzzle) can create interaural frequency dependent differences of the order of 5 to 15 dB for the open ear (Mehrgardt and Mellert, 1977). Transient impulses from the air rifles will have varied spectral content which interact with the diffraction about the head and the filtering characteristics of a person’s ear canal.

The microphones used in this study had ½-inch diameters because we did not know the approximate impulse levels prior to the study. We elected to use 1/2″-inch microphones instead of the more conventional microphones in order to maximize signal-to-noise ratio. Microphones of this size require a compromise between avoiding diffraction effects that would result from having the microphone pointed toward the direction of propagation (i.e., normal incidence of the diaphragm to the sound source) and the signal cancellation effects associated with narrow wavefronts traveling across the diaphragm surface if the diaphragm is oriented at grazing incidence to the sound source (see Rasmussen, et al., 2009 for more information). We utilized grazing incidence in the current study, realizing that this could result in attenuation of peak amplitudes if the air rifles produced a very narrow wavefront. Follow-up measurements (data not presented) with many of the same air rifles and with 1/4-inch microphones at grazing incidence, and ½-inch microphones at both grazing and normal incidence revealed small (~ 1 dB) differences with respect to both peak and equivalent continuous levels. Although the effects observed with air rifles were small, this finding cannot be expected to generalize to conventional combustion-based rifles.

## SUMMARY

The noise level from the air rifles evaluated in this study can be hazardous to hearing. Air rifles are often the entry level rifle into the life-time shooting habits of adults and first-learned health behaviors are more likely to generalize over place and time (Bouton, 2000). The consistent use of an electronic level-dependent hearing protector is recommended since these types of devices will provide audibility and auditory protection during each shot experience, and will contribute towards the development of positive hearing health behaviors in the future when shooting more hazardous firearms.

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## Abbreviations

| | |
|---|---|
| **ACGIH** | American Conference of Governmental Industrial Hygienists |
| **AHAAH** | Auditory Hazard Assessment Algorithm for Humans |
| **cm** | centimeter |
| **CI** | confidence interval |
| **$CO_2$** | Carbon Dioxide |
| **dB** | decibel |
| **DoD** | Department of Defense |
| **DRC** | damage risk criteria |
| **EPA** | Environmental Protection Agency |
| **fps** | feet per second |
| **JROTC** | Junior Reserve Officer’s Training Corp |
| **kHz** | kilohertz |
| **$L_{Aeq8}$** | A-weighted, 8-hour equivalent continuous levels |

| | |
|---|---|
| **$L_{Aeq75}$** | A-weighted, 8-hour equivalent continuous levels normalized to 75 dBA exposure criterion |
| **mm** | millimeter |
| **MPE** | maximum permissible exposure |
| **NIOSH** | National Institute for Occupational Safety and Health |
| **OSHA** | Occupational Safety and Health Administration |
| **SPL** | sound pressure level |
| **US** | United States |
| **WHO** | World Health Organization |

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**Figure 1.**
Youth target shooting with air guns and eye protection.

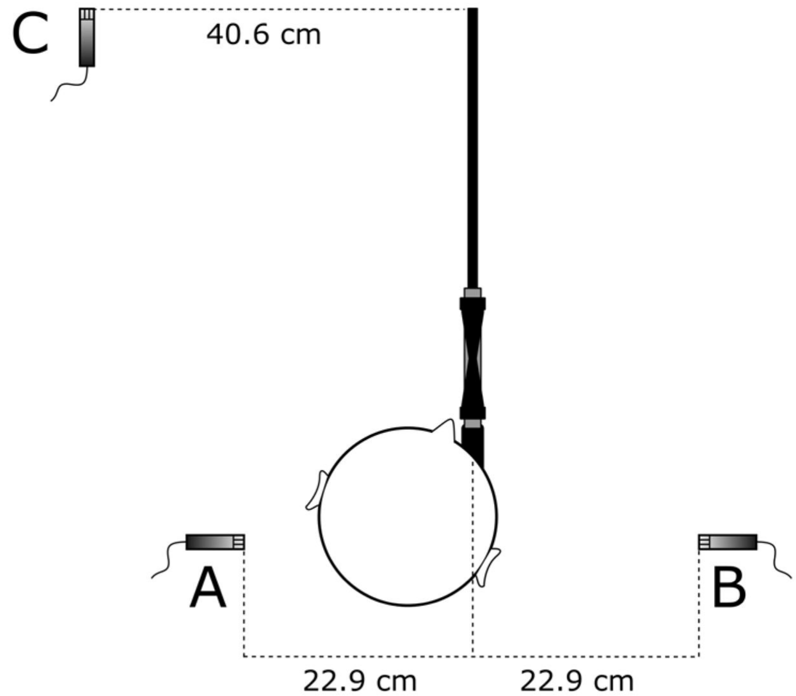


**Figure 2.**
Microphone positions relative to air rifle; A) left ear microphone, B) right ear microphone and C) muzzle microphone.

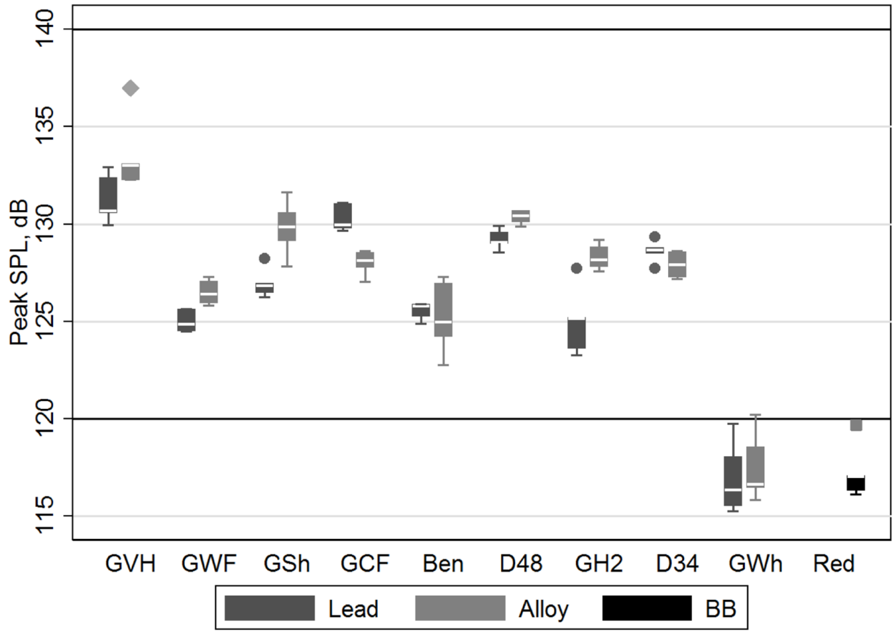


**Figure 3.**
Boxplot of air gun peak sound pressure levels for the left ear shaded for each of the three ammunition load types and referenced to 120 dB and 140 dB peak limits.

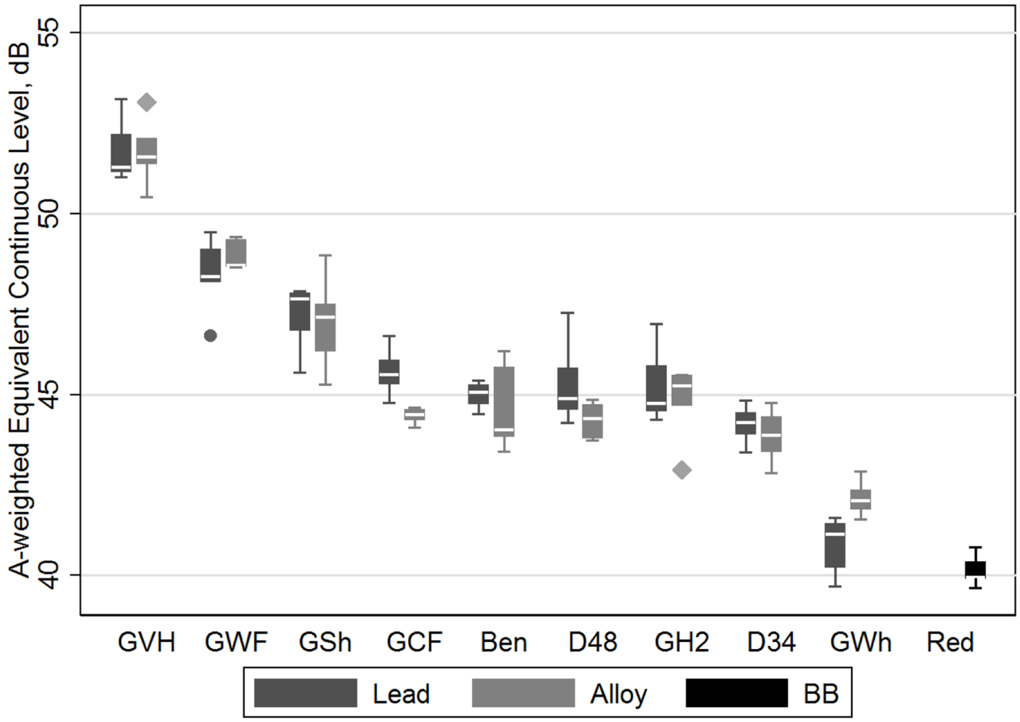


**Figure 4.**
Boxplot of air gun $L_{Aeq8}$ for the left ear shaded for each of the three ammunition load types.

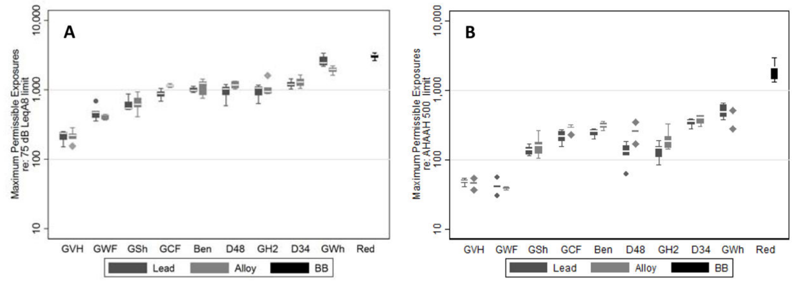


**Figure 5.**

Boxplot of air gun maximum permissible exposures for EPA/WHO 75 dB $L_{Aeq8}$ (A) criteria and auditory risk results computed via AHAAH (B) for the left ear microphone shaded for each of the three ammunition load types.

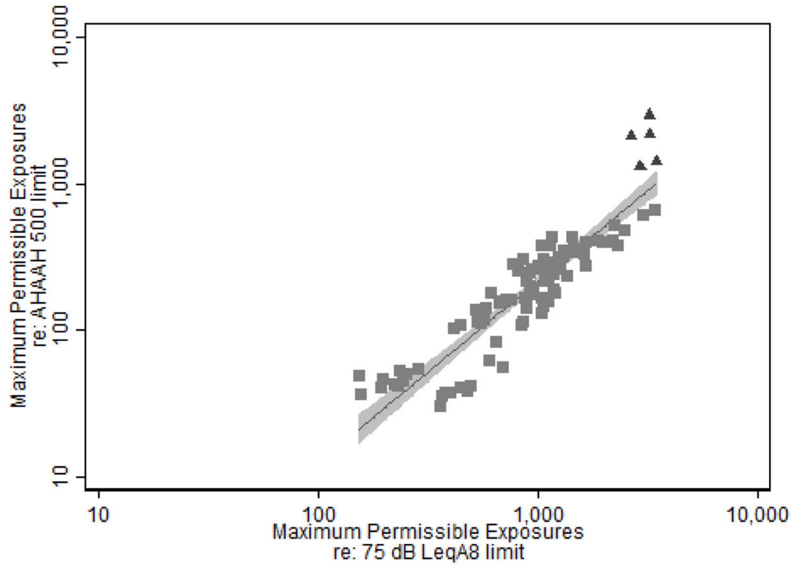


**Figure 6.**

Scatterplot and regression of logarithmically-transformed MPE values across damage-risk criteria. The shaded region represents the 95 % confidence interval for the solid linear regression line. Square symbols represent values from air guns. Triangles represent values from the Red Ryder, which uses a mechanical spring instead of compressed air. Data from the left ear microphone location are presented.

## Table 1

Description of air rifles used in the measurement of impulses. Muzzle to ear level microphone distances are also noted.

| Manufacturer (Label Key) | Model | Caliber | Suppressor | Labeled Velocity (fps) | Distance Muzzle to Ear Microphones (cm) |
|---|---|---|---|---|---|
| Benjamin (Ben) | Trail NP XL | .177 | No | 1500 | 109.2 |
| RWS (D48) | Diana 48 | .177 | No | 1100 | 90.2 |
| Gamo (GCF) | CFX | .177 | Yes | 1200 | 97.8 |
| Gamo (GH2) | Hunter 220 | .177 | No | 1000 | 91.4 |
| Gamo (GSh) | Shadow | .177 | No | 1250 | 97.8 |
| Gamo (GVH) | Varmint Hunter HP | .177 | No | 1400 | 99.1 |
| Gamo (GWF) | Whisper Fusion | .177 | Yes | 1300 | 104.1 |
| Gamo (GWh) | Whisper | .177 | Yes | 1000 | 100.3 |
| RWS (D34) | Diana 34B | .177 | No | 1000 | 102.9 |
| Daisy (Red) | Red Ryder | BB (.177) | No | 350 | 81.3 |

**Table 2**

Mean peak sound pressure levels for each ammunition load at each microphone location.

| Manufacturer Model (Label Key) | Ammunition Load | Microphone Location Peak dB SPL Mean (SD) | | |
|---|---|---|---|---|
| | | Muzzle | Left Ear | Right Ear |
| Benjamin Trial NP XL (Ben) | Alloy | 136.7 (1.8) | 125.2 (1.9) | 125.7 (1.9) |
| | Lead | 139.9 (0.7) | 125.6 (0.5) | 126.4 (0.7) |
| RWS Diana 48 (D48) | Alloy | 142.9 (0.4) | 130.4 (0.3) | 130.0 (0.2) |
| | Lead | 142.2 (0.8) | 129.2 (0.5) | 128.5 (0.8) |
| Gamo CFX (GCF) | Alloy | 140.3 (0.4) | 128.0 (0.6) | 128.9 (0.4) |
| | Lead | 141.9 (0.3) | 130.3 (0.7) | 130.9 (0.4) |
| Gamo Hunter 220 (GH2) | Alloy | 140.6 (0.2) | 128.3 (0.6) | 127.3 (0.9) |
| | Lead | 135.5 (1.8) | 125.0 (1.8) | 124.1 (1.3) |
| Gamo Shadow (GSh) | Alloy | 139.7 (0.6) | 129.8 (1.1) | 129.4 (1.0) |
| | Lead | 136.9 (0.5) | 127.0 (0.8) | 128.0 (0.8) |
| Gamo Varmint Hunter HP (GVH) | Alloy | 143.7 (4.5) | 133.5 (2.0) | 132.4 (1.0) |
| | Lead | 141.4 (0.5) | 131.3 (1.3) | 131.8 (0.6) |
| Gamo Whisper Fusion (GWF) | Alloy | 132.2 (0.4) | 126.5 (0.6) | 126.4 (1.0) |
| | Lead | 126.9 (1.6) | 125.0 (0.6) | 125.3 (1.1) |
| Gamo Whisper (GWh) | Alloy | 124.6 (1.3) | 117.6 (1.8) | 118.4 (1.5) |
| | Lead | 119.4 (1.6) | 117.0 (1.9) | 117.8 (1.6) |
| RWS Diana 34B (D34) | Alloy | 138.2 (0.3) | 127.9 (0.6) | 128.1 (0.5) |
| | Lead | 139.2 (0.3) | 128.6 (0.6) | 129.2 (0.5) |
| Total | Alloy | 137.9 (5.6) | 127.7 (4.2) | 126.3 (7.3) |
| | Lead | 135.8 (7.6) | 126.6 (4.2) | 126.9 (4.2) |
| Daisy Red Ryder (Red) | BB | 121.4 (0.9) | 117.3 (1.4) | 117.2 (1.5) |