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Auditory risk estimates for youth target shooting

Deanna K. Meinke[*], **William J. Murphy**[†], **Donald S. Finan**[*], **James E. Lankford**[‡], **Gregory A. Flamme**[§], **Michael Stewart**[#], **Jacob Soendergaard**[^], and **Trevor W. Jerome**[†]

[*]Audiology and Speech-Language Sciences, University of Northern Colorado, Greeley, USA

[†]Division of Applied Research and Technology, National Institute for Occupational Safety and Health, Cincinnati, USA

[‡]Allied Health and Communication Disorders, Northern Illinois University, DeKalb, USA

[§]Department of Speech Pathology and Audiology, Western Michigan University, Kalamazoo, USA

[#]Department of Communication Disorders, Central Michigan University, Mount Pleasant, USA

[^]G.R.A.S. Sound & Vibration, Twinsburg, USA

Abstract

Objective—To characterize the impulse noise exposure and auditory risk for youth recreational firearm users engaged in outdoor target shooting events. The youth shooting positions are typically standing or sitting at a table, which places the firearm closer to the ground or reflective surface when compared to adult shooters.

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 suggested by the World Health Organization (1999) for children.

Study sample—Impulses were generated by 26 firearm/ammunition configurations representing rifles, shotguns, and pistols used by youth. Measurements were obtained relative to a youth shooter's left ear.

Results—All firearms generated peak levels that exceeded the 120 dB peak limit suggested by the WHO for children. In general, shooting from the seated position over a tabletop increases the peak levels, L_{Aeq8} and reduces the unprotected maximum permissible exposures (MPEs) for both rifles and pistols. Pistols pose the greatest auditory risk when fired over a tabletop.

Conclusion—Youth should utilize smaller caliber weapons, preferably from the standing position, and always wear hearing protection whenever engaging in shooting activities to reduce the risk for auditory damage.

Correspondence: Deanna K. Meinke, Audiology and Speech-Language Sciences, University of Northern Colorado, Campus Box 140, Greeley, CO 80639, USA. Deanna.Meinke@unco.edu.

Preliminary findings from this study were presented at the 38th Annual National Hearing Conservation Association Conference; St. Petersburg, Florida, USAL. (Meinke et al, 2013b).

Declaration of interest: Jacob Soendergaard is an employee of G.R.A.S. Sound and Vibration, a manufacturer of sound measurement equipment, some of which was used in this research study.

Keywords

Firearms; youth; recreational shooting; noise-induced hearing loss; auditory risk; impulse noise

Youth are actively engaged in the use of recreational firearms beginning at a young age as reported in the companion paper by Stewart et al (2014). Youth in this context refers to both child and adolescent shooters under the age of 18 years who engage in the sport. Organized instruction, practice, and competitions are offered by multiple organizations such as the National Skeet Shooting Association, National 4-H Shooting Sports, Boy Scouts of America, Scholastic Clay Target Shooting Program, National Rifle Association, as well as wildlife conservation groups including Ducks Unlimited, Pheasants Forever, Quail Forever, and the National Wild Turkey Federation. Youth are encouraged to participate in target shooting activities at local indoor and outdoor shooting ranges, or at informal rural venues such as farms and ranches under the mentorship of adult shooters. These events typically have bystanders and spectators nearby the shooters.

Numerous studies have suggested an association between firearm use and high-frequency hearing loss in youth (Axelsson et al, 1981, 1987; Kramer & Wood, 1982; Holmes et al, 1997). More recently, evidence of high-frequency hearing loss consistent with noise-induced hearing loss (NIHL) has been reported through analysis of National Health and Nutrition Examination Survey (NHANES) audiometric data by Niskar et al (2001) and Henderson et al (2011). The Henderson study (n = 1789) noted that firearm use was reported by 15.1% of females and 42.4% of males of the 2005–2006 NHANES participants aged 12–19 years. The odds ratio of the firearm-exposed youth exhibiting noise-induced threshold shift (NITS) was 1.43 (CI = 0.94 to 2.17).

The instantaneous peak sound pressure level (SPL) is commonly used to reference the potential auditory hazard from impulse signals generated by firearms. For adults in the United States, peak SPLs that exceed a limit of 140 dB are incorporated into regulations or recommendations by the U.S. Occupational Safety and Health Administration (OSHA), 1983; the National Institute for Occupational Safety and Health (NIOSH), 1998; and the Department of Defense (MIL-STD-1474D). The World Health Organization (WHO) (Berglund, 1999) also provides recommendations for peak SPLs. Only the WHO guidelines specifically address the risk to children from impulse noise and recommend that impulse levels not exceed a more conservative limit of 120 dB peak SPL. Peak levels exceeding these limits and ranging from 141 to 175 dB at the location of the shooter or bystanders in the immediate area have been reported (Flamme et al, 2011; 2009b; Kramer, 1990; Odess, 1972).

Peak SPL values do not fully represent the potential damage to the auditory system. Acoustic characteristics of the sound exposure such as the total energy contained in the impulse, frequency spectrum, the pressure-time waveform, and reverberant decay duration of the time waveform influence auditory risk estimates (see Flamme et al, 2009a for a review). The auditory hazard of an impulse can be characterized with the A-weighted 8-hour equivalent energy level, L_{Aeq8}, as proposed by Atherley and Martin (1971). The L_{Aeq8} criterion is computed by filtering the acoustic signal to approximate the transfer function of the human ear at 40 phons and integrating the energy over the duration of the impulse and normalizing the exposure to an 8-hour time period. This approach has been used by most regulatory agencies for establishing permissible occupational noise exposure limits for adults. Government agencies reference an allowable or recommended time weighted average (TWA) for both continuous and impulse/impact noise of 85 dBA (NIOSH, 1998; OSHA 1983). These approaches also are based upon a political compromise that estimates the percentage of the workforce (Prince et al, 1997) at risk of developing a 25-dB average hearing impairment over a working lifetime (NIOSH, 1998). No specific limits have been developed for children or adolescents; however the U.S. Environmental Protection Agency (EPA) (1973) and WHO (1999) recommend that noise exposure should not exceed 70-dB equivalent continuous level (L_{eq}) averaged over a 24-hour period, which is equivalent to 75 dB L_{Aeq8} for an 8-hour period. The 75 dB L_{Aeq8} criterion is based upon the auditory injury threshold at 4 kHz (ISO-1999, 1990; ANSI S3.44, 2006; EPA, 1973).

The auditory risk of noise exposure to civilian firearms (Flamme et al, 2009b) and starter pistols (Meinke et al, 2013) have been described using commonly referenced damage risk criteria (DRC) developed for adults. Auditory risk estimates vary as a function of firearm, ammunition, listener location, and use of hearing protective devices.

Youth appear to be just as likely to shoot firearms commonly used by adults and are not limited to exposure from small caliber firearms (Stewart et al, 2014). Ammunition choice will vary between the preferred load selected for hunting and the load used for target shooting unless specifically sighting in a firearm for hunting purposes. The listening position for youth shooters will differ from that of an adult. First, as a function of height when standing, younger youth are more likely to have their ear and muzzle of the firearm closer to the ground as compared to an adult. Second, when shooting a pistol, the shorter arm lengths for youth may position the muzzle of the firearm closer to the shooter's ears. This situation may also arise with shotguns or rifles with a shorter "length of pull" (LOP) on models designed specifically for youth. LOP refers to the distance between the face of the trigger and the recoil/butt plate of the stock. Third, when target shooting, youth are often seated at a table and use the table to help stabilize the firearm in an effort to improve aim and facilitate physical safety. This shooting position introduces a hard reflective surface into the acoustic environment, especially when the muzzle of the firearm does not extend beyond the edge of the tabletop (Figure 1).

Methods

Design

The research is a descriptive study designed to investigate the auditory risk for youth target shooters. Measurements were obtained at the approximate level of a youth shooter's left ear, both standing in an open field and over a tabletop. The left ear was selected due to the head-shadow effect for right-handed shooters when shooting rifles and shotguns.

Firearms and ammunition

Impulses were generated by 21 firearms, including rifles (n = 11), shotguns (n = 6), and pistols (n = 4) used by youth. Firearms were selected based upon the study by Stewart et al (2014) and availability. Ammunition varied for each firearm and more than one type of ammunition or choke (used to constrict the muzzle for tighter shot patterns) configuration was investigated for five firearms, resulting in a total of 26 shooting configurations. Specific firearms with their respective ammunition/configuration are summarized in Table 1.

Instrumentation

Impulse recordings were made outdoors using a 1/8-inch prepolarized pressure microphone (G.R.A.S. Type 40DD) with an approximate sensitivity of 1 mV/Pa, and oriented at grazing incidence to the sound source. This microphone affords a useable frequency range up to 140 kHz and a dynamic range extending to 186 dB peak SPL. The microphone was equipped with 1/4-inch preamplifier (+G.R.A.S. Type 26AC) capable of carrying the potentially large signals without overload or slew-rate limitations. Microphones were calibrated using a piston phone (G.R.A.S. 42 AP) before and after a continuous six-hour measurement period. A 2-channel constant voltage power module (G.R.A.S. Type 12AA) with adjustable gain (+ 20, 0, −20 and −40 dB) and a dynamic range of ±42 V, provided power to the front end equipment. Data were sampled at an 800-kHz sampling rate with a National Instruments PXI-6120 module data acquisition system. A 64 Msample on-board buffer was used to record 50 ms of data prior to the impulse, with a total data window length of 500 ms. The data were sampled with 16-bit resolution, giving a 90-dB dynamic range free from spurious contamination. Data acquisition was controlled by a custom Lab View program with an integrated calibration routine and trigger control. The data were saved in text files for post-processing and analysis in MATLAB.

Experimental procedure

A minimum of five shots were fired on a horizontal plane for each of the two shooting simulations for each firearm. Firing was done by experienced adult shooters who were standing or sitting in a way to place their torsos at the approximate height of a youth shooter. The microphone was positioned relative to a simulated sitting or standing youth shooter. The position was selected to represent the left ear of a right-handed youth shooter. For the standing position condition, the microphone was placed at a height of 110 cm above the ground at ear level to correspond with ear-level of a youth recreational shooter in the standing position. The microphone was lowered to a height 101 cm above the ground for the seated simulation. A hard-surfaced table (183 × 76 cm surface) with a height of 74 cm was placed in front of the seated shooter. Only rifles and pistols were fired from the seated condition. Pistols were fired with arms partially extended using a two-handed grip with the muzzle positioned equi-distance from the right and left ears. The left-ear microphone was 47 cm from the trigger of the pistol. Muzzle locations relative to the table edge varied, some were recessed from the table edge while others extended beyond the edge of the table. All of the rifles with the exception of the Rossi Trifecta .22 extended beyond the edge of the table from 2 to 23 cm. The Rossi Trifecta .22 muzzle was recessed 3 cm. Pistol muzzles were recessed 20–23 cm.

Analysis

Post-processing of the impulse text data was accomplished with National Instruments DIAdem software, and subsequently transfered to MATLAB for scaling into Pascal (Pa) units using software routines orginally developed in the NIOSH Taft Laboratories (Zechmann, 2012). Mean peak sound pressure level and dB L_{Aeq8} values were calculated for the five shots fired under each measurement condition. L_{Aeq8} was computed in terms of the following equation:

$$L_{Aeq,8hr}=10\log_{10}\left(\frac{1}{t_2-t_1}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}dt\right)+10\log_{10}\left(\frac{t_2-t_1}{T_{8hr}}\right)+10\log_{10}(N)$$

where the reference pressure is p_0 = 20 −μPa, $p_A(t)$ is the A-weighted pressure signal as a function of time, t_1 and t_2 define the duration of the impulsive event, and N is the number of events. Setting the value of T_{8hr} = 28 800 normalizes the energy of the event whose duration is measured in seconds to the equivalent 8-hour exposure. Maximum permissible exposures (MPEs) were determined using an 85-dB L_{Aeq8} criterion (DTAT, 1983) referencing the following equation:

$$\text{MPE}=10^{(85-LAeq8)/10}$$

where MPE represents the maximum number of permissible exposures (unprotected), and L_{Aeq8} is the mean equivalent 8-hour A-weighted level produced in the measurement condition. Truncation was applied to convert non-integer MPE values into integer values.

Results

Rifles

Measurements for rifles fired in the standing and seated tabletop positions are summarized by mean peak level rank order in Table 2. Mean peak SPLs and L_{Aeq8} values ranged from 139.6 dB (L_{Aeq8} = 63.8 dB) to 163.6 dB (L_{Aeq8} = 85.7 dB) standing, and 140.4 dB (L_{Aeq8} = 64.8 dB) to 166.0 (L_{Aeq8} = 88.2 dB) seated at table. MPEs are highest for the smaller caliber .22 and .17 caliber rifles (20–133 shots) and lowest (1–2 shots) for higher caliber rifles regardless of shooting position. Comparison of the standing versus seated positions reveals a negligible effect (< 1 dB mean peak SPL difference) for all rifles fired over a tabletop with the exception of the Remington 742 .30–06 caliber, which had a 2.4 dB peak SPL increase when fired over the table. This increase in peak SPL for this particular firearm when shot over the table is likely due to the shorter barrel (18 vs. 22–24 inches). The slightly recessed position (3 cm) relative to the tabletop edge for the Rossi Trifecta .22 muzzle resulted in the highest mean peak level of the .22 caliber rifles.

Shotguns

Shotguns were only measured for the youth standing position and are summarized in Table 3. Mean peak levels and L_{Aeq8} values varied from 151.8 dB (L_{Aeq8} = 75.8 dB) to 161.6 dB SPL (L_{Aeq8} = 83.3 dB). MPEs were highest for the Mossberg 183KE .410 with 7–8 shots permitted and lowest for the Remington 11–87 12 ga. (1 shot). The acoustic characteristics of shotguns are not orderly as a function of caliber/gauge, but vary as a function of manufacturer/model and ammunition. Peak SPLs were 5.7 dB higher for the New England SBI .410, which produced a peak level of 157.5 dB when compared to the Mossberg .410 which produced peak levels of 151.8/151.9 dB, depending upon ammunition fired. It is worth noting that the New England SBI .410 also had a barrel that was 3-inches shorter than the Mossberg .410. Peak SPL values for .20 gauge shotgun models varied as much as 4.9 dB, while 12 gauge models varied by 5.8 dB. Ammunition influenced the mean peak SPLs and auditory risk for the Remington 870 12 ga. shotgun. The Fiocchi Golden Pheasant GPX 12 ga. 2.75-inch, 1 3/8 oz, #4 shot produced peak levels 4.5 dB higher than the Federal Target Load, 12 ga. 2.75-inch, 1 1/8 oz, #8 shot resulting in a MPE reduction from 5 to 2.

Pistols

Table 4 provides a summary of the measurements for pistols measured in the standing and seated tabletop positions. Mean peak SPL and L_{Aeq8} values ranged from 157.5 dB (L_{Aeq8} = 78.1 dB) to 168.8 dB (L_{Aeq8} = 88.5 dB) standing, and 156.3 dB (L_{Aeq8} = 77.7 dB) to 171.1 dB (L_{Aeq8} = 91.3 dB) seated at table. The two .22 models were generally consistent for peak SPL values across models when ammunition was held constant (0.4 dB) and fired from the standing position. However, when the .22 pistols were fired over a tabletop, the more recessed muzzle of the Smith & Wesson .22 produced 4.4 dB higher mean peak levels. Ammunition influences the acoustic characteristics for the .357 magnum and the .44 Magnum pistols. The smaller caliber .357 Magnum produces the highest peak level (168.8 to 171.1 dB SPL) when firing Remington .357 magnum 125 grain, Semi-JKTD, hollow point bullets from either shooting position. For the Colt Anaconda .44 Magnum, mean peak levels were 6.5 dB higher (standing) and 8.4 dB higher (table-top) when loaded with Hornady vs. Winchester ammunition. The Ruger GP 100 .357 produced peak levels 4.1 dB higher (standing) and 5.1 dB higher (tabletop) when firing the Remington .357 Magnum ammunition compared to the Winchester .38 Special ammunition. Shooting over the tabletop increased mean peak levels by 1.3 to 4.0 dB with the exception of the Ruger MK .22 which had a slightly lower (0.8 dB) mean peak SPL when fired from the seated tabletop position as compared to the standing position. In terms of auditory risk, the MPE were 3 to 5 for the .22 pistols and 0 to 1 for all other pistols.

Auditory risk

In general, shooting from the seated position over a tabletop increases peak levels, L_{Aeq8} and reduces the unprotected MPEs for both rifles and pistols. A comparison of auditory risk metrics across firearm types is provided in Table 5.

Shooting a pistol over a tabletop increases the effective peak levels up to 4 dB and exposure, up to 3.4 dB (Figure 2). Shooting a rifle over a tabletop also increases the peak levels and exposure, but to a lesser degree.

Larger caliber/gauge rifles, shotguns and pistols produce greater auditory risk than smaller caliber/gauges of firearms. Pistols pose the greatest auditory risk when firing (without hearing protection worn) over a tabletop. Rifle mean peak levels vary across guns by as much as 20 dB, resulting in considerably greater exposure for rifles that do not fire .22 caliber ammunition. For both rifles and pistols, the cumulative energy reaching the ear is more hazardous when shooting without hearing protection over a tabletop, as opposed to standing (Figure 3).

Discussion

An auditory hazard exists when youth shoot both small caliber and large caliber/gauge firearms without wearing hearing protection. All of the firearms exceeded the 140-dB instantaneous peak level criteria recommended for adults, with the exception of the .22 caliber Remington 514 rifle (139.6 dB). All of the firearms exceeded the 120-dB peak level criterion recommended by the World Health Organization (WHO) in 1999 for children. In fact, the majority of the firearms used for hunting by youth exceed a peak level of 151 dB SPL. Only .22 caliber firearms had L_{Aeq8} values below 75 dBA for a single shot; however peak values were 140 dB SPL or higher. Shooters are more likely to use hearing protection when target shooting, a situation where the .22 caliber rifle and pistol are commonly used. However, .22 caliber ammunition is comparatively inexpensive, which leads to increased number of shots per shooting event. The firearms used for hunting produce a greater auditory risk for individual shots and are more likely to be fired without hearing protectors in place by youth Model (Stewart et al, 2014). Hunters of any age have an ever-increasing choice of affordable electronic and level-dependent hearing protection. Like safety glasses or prescription eyewear, a conscious effort must be made to learn to hear the world through different auditory lenses (filters). Localization is altered and detection of game can be enhanced.

The results from this study highlight the advantages of youth shooting smaller caliber firearms when possible in order to minimize auditory risk. It may be desirable to reserve the use of larger caliber/gauge weapons for hunting situations where the additional power is necessary. Practice with larger caliber/gauge weapons can perhaps be limited to developing the skill needed to utilize the weapon safely, learning to manage recoil and achieving target accuracy.

Auditory risk is also greater when the muzzle of the firearm is closer to the ear. It is easier for youth to physically handle smaller weapons, which makes shooting pistols more advantageous for youth learning to shoot. Rifles and shotguns with shorter barrels also increase the auditory hazard. Revolver pistols present an increased auditory hazard as do rifles with muzzle brakes because exhaust gases escape to the side of the chamber or muzzle directing more energy towards the shooter’s ears (Tubbs & Murphy, 2003; Murphy et al, 2012). When possible, firearms should be selected that place the muzzle at a greater distance from the ear.

Youth often gather in groups to engage in shooting events. Sitting side-by-side and firing over a tabletop exposes youth to higher impulse peak levels due to shooting over a hard reflective surface. In addition, the youth are exposed to unnecessary impulses from nearby shooters, which are more hazardous to a bystander (Flamme et al, 2011; Murphy et al, 2012). Auditory risk can be reduced by having youth shoot from a standing position with wide-spacing between shooters to limit bystander exposure. Barriers between shooters could potentially reduce exposures to other shooters. If physical support is needed for the firearm, alternatives to a wide tabletop such as a narrow bench or plank might be useful in terms of reducing the reflection of the muzzle blast off a hard surface. Other situations that place a firearm muzzle over a hard reflective surface when hunting should also be avoided, such as shooting over the hood of a vehicle or when shooting from the ground over a cement surface.

Hearing protection devices should be utilized whenever youth shoot any firearm. Dual hearing protection (earplug and earmuff) are recommended for adults (Tubbs & Murphy, 2003; NIOSH, 2009) and should also be considered for young shooters in terms of greatest protection.

On the face of it, dual protection balances towards more protection and less audibility of important game sounds, firearm function, hunting partner communications, situational and environmental cues, critical to enjoyment and safety of the sport. The option of an electronic level-dependent muff in combination with a passive plug can offset the loss in audibility, and has been mentioned by Murphy in prior publications (Murphy & Tubbs, 2007; NIOSH 2009).

Audibility should be considered a pre-requisite when selecting hearing protection for youth, whether for target or hunting purposes. It is important for shooters of all ages to maintain awareness of events taking place around them, and the reduction in this awareness can be a barrier to the use of hearing protection. Level-dependent hearing protection devices (electronic and passive) have been designed to offer both audibility and impulse signal protection (Berger & Hamery, 2008; Murphy et al, 2012). Providing these types of HPDs is critical for youth firing weapons with a crucial need to hear practical instruction, safety warnings, and general communications when handling loaded firearms at young ages. The option of an electronic level-dependent muff in combination with a passive ear plug can potentially offset the loss in audibility from a single passive device, while increasing the attenuation of hazardous high-level impulsive sounds (Kahn et al, 2013). It is also important to establish early the habit of using hearing protectors while shooting.

The findings from this study can be integrated into hearing loss prevention education and training for both adults and youth. The public will be able to understand specific peak impulse levels, especially as they relate to specific firearms. It is suggested that the MPE values not be used as a point of reference for actual permissible number of unprotected shots for youth, since these are based upon unprotected adult criterion. Youth can be taught that one shot from mid and large caliber/gauge firearms may contain acoustic energy equivalent to one day of work-related noise exposure when referencing 85 dB L_{Aeq8} criteria. Furthermore they can be taught that exposures above 140 dB can produce tinnitus, temporary and permanent threshold shifts in hearing, as well as damage to the structures of the auditory system. With the exception of the .22 caliber rifle, a single shot from the guns in this study will produce more sound exposure in 10 milliseconds than most people would accumulate in a full day. A single shot from the more intense firearms in this study produce more total sound exposure in 10 milliseconds than most people have in a month.

This study was conducted outdoors and results cannot be generalized without further investigation to indoor shooting environments. Auditory hazard will likely be increased due to the additional surfaces reflecting the primary impulse back to the shooter's ears. The height of a youth relative to the ground and tabletop surface will also change with age which will influence the acoustic characteristics of the impulse signal arriving at the ear of the shooter.

Summary

The impulsive levels produced by firearms used by youth are hazardous to the shooter when fired from either the standing or seated tabletop shooting position when hearing protection is not worn. Auditory risk is increased for the seated tabletop position when compared to the standing position for both rifles and pistols due to the reflective surface of the tabletop. The unprotected MPE are under 10 for all firearms except the .22 and .17 caliber rifles and 0–1 for larger caliber firearms, regardless of shooting position. The choice of firearm, ammunition, and shooting position interact to influence the actual auditory risk to the youth shooter. Level-dependent (passive or electronic) hearing protection devices are suggested for youth and adult mentors to enhance audibility and communication during shooting activities. It is critical that any hearing protector worn be sized appropriately and seal well. Persons providing firearm and hunter safety programs for youth are encouraged to include content specific information relative to firearm sound levels and appropriate hearing protector options in an effort to prevent noise-induced hearing loss and tinnitus in young recreational shooters.

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Abbreviations

DRC	Damage risk criteria
ga	gauge
L_{Aeq8}	A-weighted, 8-hour equivalent continuous levels
L_{eq}	Level equivalent
MPE	Maximum permissible exposure
NHANES	National Health and Nutrition Examination Survey
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
SPL	Sound pressure level
TWA	Time-weighted average

WHO World Health Organization

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Figure 1.
Example of youth target shooting position; sitting at table and wearing electronic earmuffs.

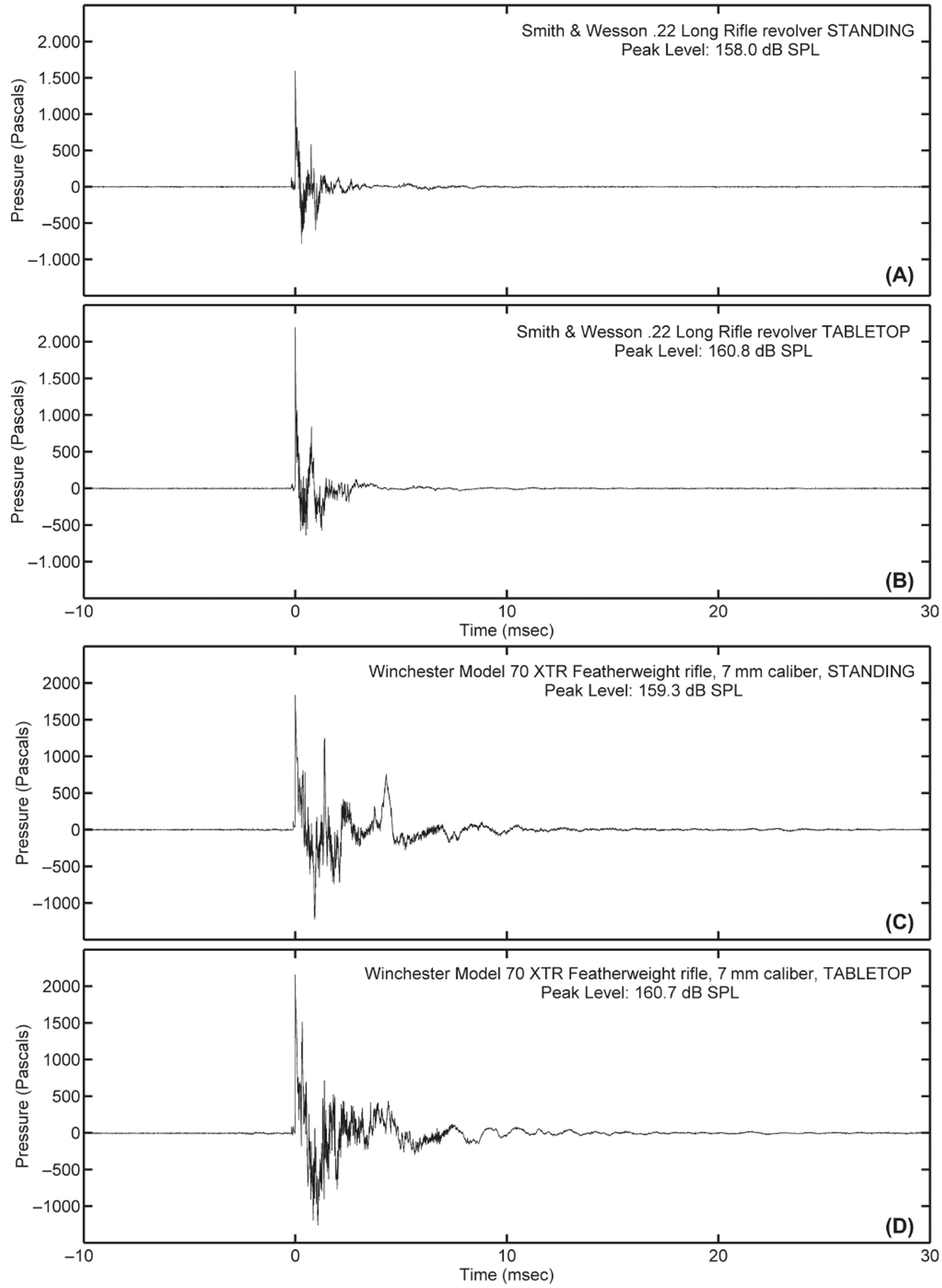

Figure 2.

Impulse waveform comparisons for the Smith & Wesson .22 long rifle revolver (A, B) and the Winchester 70 XTR Featherweight rifle (C, D); shot from the standing (A, C) and the tabletop (B, D) shooting positions.

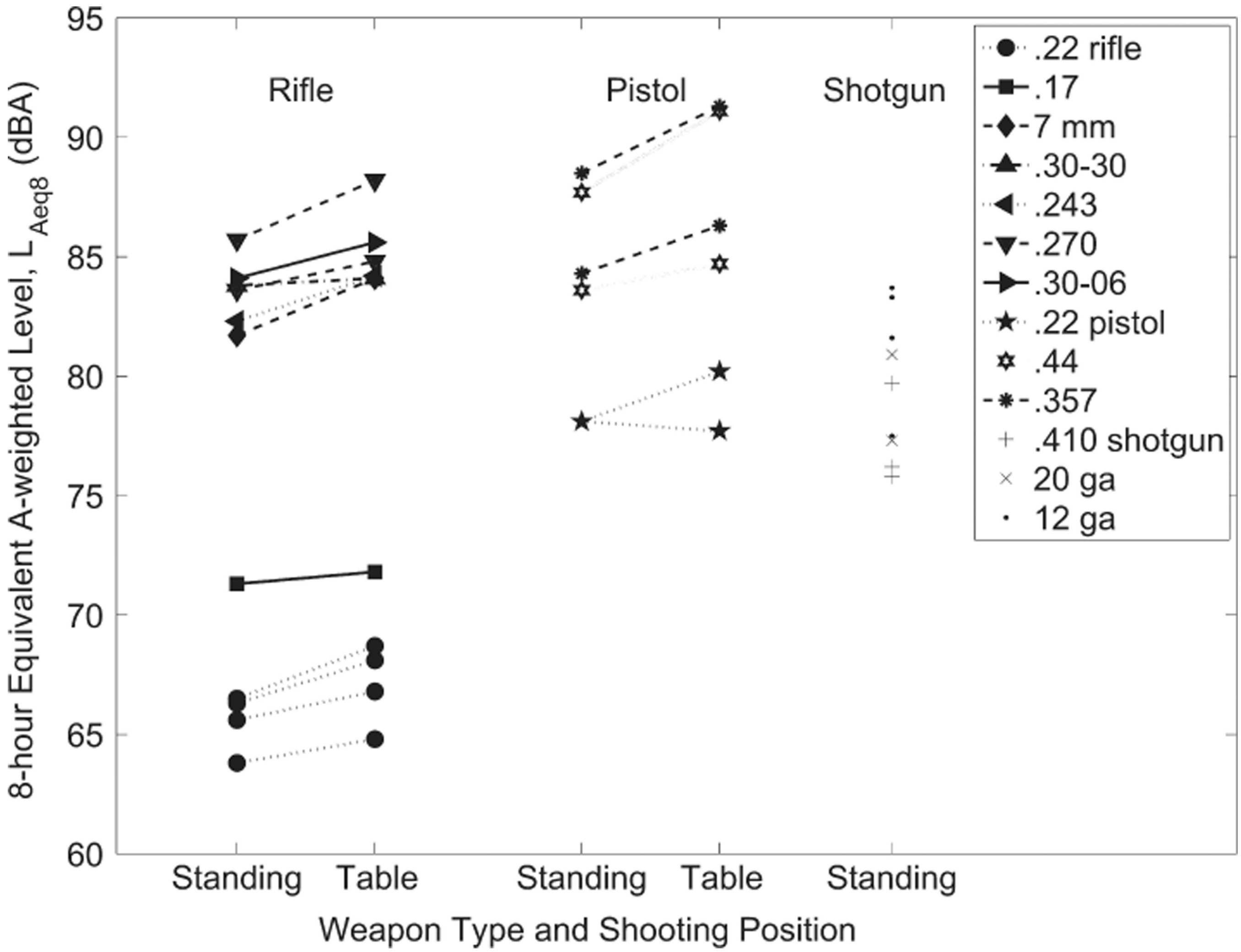

Figure 3.
Comparison of 8-hour equivalent A-weighted levels for rifles, shotguns, and pistols when fired from a standing position and seated tabletop position. Note: In some instances the same firearm was fired with more than one ammunition type, as indicated in Table 1.

Table 1

Description of firearms and ammunition used in the measurement of impulses.

Manufacturer	Model	Gauge/caliber	Ammunition	Action	Barrel length (inches)
Rifles					
Remington	514	.22	Remington .22 Thunderbolt 40 grain, lead round nose	Bolt	24
Mossberg	702 Plinkster	.22	Remington .22 Thunderbolt 40 grain, lead round nose	Semi-auto	18
Ruger	10/22	.22 Long rifle	Remington .22 Thunderbolt 40 grain, lead round nose	Semi-auto	18
Rossi	Trifecta	.22	Remington .22 Thunderbolt 40 grain, lead round nose	Single shot	18.5
Marlin	917 VS	.17	Hornady .17 HMR 20 grain XTP	Bolt	22
Winchester	70 XTR Featherweight	7 mm Mauser	Lellier & Bellot 7 mm Mauser (7 × 57), 173 grain	Bolt	22
Winchester	94	.30–30	Remington .30–30 Core-Lokt, 150 grain, Soft point	Lever	20
Rossi	Trifecta	.243	Remington .243 Winchester Core-Lokt PSP, 100 grain	Single shot	22
Browning	X-Bolt	.30–06	Winchester .30–06 SPRG 150 grain, Power point	Bolt	22
Steyer-Daimler	Mannlicher	.270	Remington .270 Winchester, Express Core-Lokt, 150 grain, Soft point	Bolt	20
Remington	742 Carbine Woodsmaster	.30–06	Remington .30–06 Springfield, Express Core-Lokt, 165 grain	Semi-auto	18
Shotguns					
Mossberg	183KE	.410 caliber	Winchester Super X HS .410 2.5”, ½ oz, #4 *and* Winchester Super X HS .410 3-inch, 11/16 oz, #7.5	Bolt	25 with 2.75-inch choke
Pietro Beretta	Pietro Beretta	20 gauge	Remington Express Long Range, 20 ga. 2.75-inch, 1 oz, #6	Single shot	28
Remington	870 Express Magnum	12 gauge	Federal Target Load 12 ga., 2.75-inch, 1 1/8 oz, #8 *and* Fiocchi Golden Pheasant GPX, 12 ga. 2.75-inch, 1 3/8 oz, #4	Pump	26
New England	Partner SBI	.410 caliber	Remington Express Long Range, .410, 3-inch, 11/16 oz, #7.5	Single shot	22
Rossi	Trifecta	20 gauge	Winchester Super X, 20 ga. 2.75-inch, 1 oz, #5	Single shot	22
Remington	11–87	12 gauge	Winchester Supreme 12 ga., 3-inch, 1 ¾ oz, #5	Semi-auto	21.75 with *and* 21 without choke
Pistols					
Ruger	MK	.22 Long Rifle	Remington .22 Thunderbolt 40 grain, lead round nose	Semi-auto	4.5
Smith & Wesson	Long Rifle CTG	.22 Long Rifle	Remington .22 Thunderbolt 40 grain, lead round nose	Revolver	6
Colt	Anaconda	.44 Magnum	Winchester .44 Smith & Wesson SPL, 200 grain, Silvertip HP *and* Hornady .44 Magnum 200 grain XTP	Revolver	4
Ruger	GP 100	.357 Magnum	Remington .357 Mag. 125 grain, Semi-JKTD, hollow point *and* Winchester .38 Special 125 grain, Jacketed hollow point + P	Revolver	4

Table 2

Comparison of acoustic characteristics of rifle impulses at the shooter's ear position for standing and tabletop positions; rank ordered by peak dB SPL standing position. See Table 1 for ammunition used.

		Peak dB SPL		L_{Aeq8} dB SPL		MPE	
Rifles		Standing	Tabletop	Standing	Tabletop	Standing	Tabletop
Remmington 514 .22	Mean	139.6	140.4	63.8	64.8	133	105
	(SD)	(1.0)	(1.0)	(1.2)	(0.9)	–	–
	Diff		.8		1.0		28
Mossberg 702 .22	Mean	143.0	143.6	65.6	66.8	86	66
	(SD)	(1.1)	(0.3)	(0.6)	(0.6)	–	–
	Diff		.6		1.2		20
Ruger 10/22 .22	Mean	143.4	143.7	66.5	68.7	70	42
	(SD)	(.50)	(1.3)	(0.4)	(0.9)	–	–
	Diff		.3		2.2		28
Rossi Trifecta .22	Mean	143.8	144.5	66.3	68.1	73	48
	(SD)	(1.0)	(0.7)	(1.3)	(0.8)	–	–
	Diff		0.7		1.8		25
Marlin 917 VS .17	Mean	147.1	147.5	71.3	71.8	23	20
	(SD)	(0.6)	(0.7)	(0.9)	(0.5)	–	–
	Diff		0.4		0.6		3
Winchester 70 XTR 7 mm Mauser	Mean	159.2	160.7	81.7	84.1	2	1
	(SD)	(0.2)	(0.3)	(0.4)	(0.7)	–	–
	Diff		1.5		2.4		1
Winchester 94 .30–30	Mean	160.5	161.3	83.8	84.1	1	1
	(SD)	(0.4)	(0.2)	(0.5)	(0.1)	–	–
	Diff		0.8		0.3		0
Rossi Trifecta .243	Mean	160.6	161.7	82.3	84.2	1	1
	(SD)	(0.1)	(0.1)	(0.2)	(0.2)	–	–
	Diff		1.1		1.9		0
Browning X-Bolt .30–06	Mean	161.4	162.6	83.6	84.8	1	0
	(SD)	(0.1)	(0.2)	(0.9)	(0.4)	–	–
	Diff		1.2		1.2		1
Steyer-Daimler .270	Mean	161.9	163.3	84.1	85.6	1	0
	(SD)	(0.3)	(0.1)	(0.4)	(0.3)	–	–
	Diff		1.4		1.5		1
Remington 742 .30–06	Mean	163.6	166.0	85.7	88.2	0	0
	(SD)	(0.3)	(0.5)	(0.5)	(0.5)	–	–
	Diff		2.4		2.5		0

Table 3

Acoustic characteristics of shotgun impulses at the shooter's ear position when standing; rank ordered by peak dB SPL.

Shotguns/ammunition		Standing		
		Peak dB SPL	L_{Aeq8} dB SPL	MPE
Mossberg 183KE .410 (2.5-inch, #4 shot)	Mean (SD)	151.8 (0.5)	75.8 (0.7)	8
Mossberg 183KE .410 (3.0-inch, #7.5 shot)	Mean (SD)	151.9 (0.4)	76.2 (0.3)	7
Pietro Beretta 20 ga (2.75-inch, #6 shot)	Mean (SD)	154.2 (0.8)	77.3 (0.5)	5
Remington 870 12 ga. (2.75-inch, #8 shot)	Mean (SD)	155.2 (0.3)	77.5 (0.4)	5
New England SBI .410 (3-inch, #7.5 shot)	Mean (SD)	157.5 (0.5)	79.7 (0.5)	3
Rossi Trifecta 20 ga. (2.75-inch, #5 shot)	Mean (SD)	159.1 (0.6)	80.9 (0.5)	2
Remington 870 12 ga. (2.75-inch, #4 shot)	Mean (SD)	159.7 (0.9)	81.6 (0.6)	2
Remington 11–87 12 ga. (3-inch, #5 shot) (without choke)	Mean (SD)	161.0 (0.3)	83.7 (0.6)	1
Remington 11–87 12 ga. (3-inch, #5 shot) (with choke)	Mean (SD)	161.5 (07)	83.3 (0.3)	1

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Table 4

Comparison of acoustic characteristics of pistol impulses at the shooter's ear position for standing and tabletop positions; rank ordered by peak dB SPL standing position.

		Peak, dB SPL		L_{Aeq8} dB SPL		MPE	
Pistols/(ammunition)		Standing	Tabletop	Standing	Tabletop	Standing	Tabletop
Ruger MK	Mean	157.5	156.3	78.1	77.7	4	5
.22	(SD)	(0.3)	(0.2)	(0.7)	(0.7)	–	–
(Remington .22 Thunderbolt)	Diff*		−0.8		0.6		1
Smith & Wesson LR CTG	Mean	157.9	160.7	78.1	80.2	4	3
.22	(SD)	(0.3)	(0.3)	(0.6)	(0.4)	–	–
(Remington .22 Thunderbolt)	Diff		2.8		2.1		1
Colt Anaconda	Mean	159.2	161.3	83.6	84.7	1	0
.44 Magnum	(SD)	(0.8)	(1.1)	(0.4)	(0.8)	–	–
(Winchester .44 S&W)	Diff		2.1		1.1		1
Ruger GP 100	Mean	164.7	166.0	84.3	86.3	1	0
.357 Magnum	(SD)	(0.5)	(0.5)	(0.5)	(0.2)	–	–
(Winchester .38 Special)	Diff		1.3		2.0		1
Colt Anaconda	Mean	165.7	169.7	87.7	91.1	0	0
.44 Magnum	(SD)	(1.1)	(0.6)	(1.0)	(1.0)	–	–
(Hornady .44 Magnum)	Diff		4.0		3.4		0
Ruger GP 100	Mean	168.8	171.1	88.5	91.3	0	0
.357 Magnum	(SD)	(0.6)	(0.9)	(0.4)	(0.5)	–	–
(Remington .357 Magnum)	Diff		2.3		2.8		0

* difference is lower for seated tabletop position than standing position.

Table 5

Comparison of mean peak levels, L_{Aeq8s} and MPEs for standing and seated tabletop positions by firearm type. Note: negative differences reflect higher values for the standing versus the tabletop position.

Firearm type	Condition	Peak dB SPL	L_{Aeq8} dB SPL	MPE
Rifles	Standing	139.6 to 163.6	63.8 to 85.7	0 to 133
	Tabletop	140.4 to 166.0	64.8 to 88.2	0 to 105
	(Differences)	(0.3 to 2.4)	(0.3 to 2.5)	(0 to 28)
Shotguns	Standing	151.8 to 161.5	75.8 to 83.7	1 to 8
Pistols	Standing	157.5 to 168.8	78.1 to 88.5	0 to 4
	Tabletop	156.3 to 171.1	77.7 to 91.3	0 to 5
	(Differences)	(−0.8 to 4.0)	(−0.6 to 3.4)	0 to 1