CDC
Workplace
Safety and Health

NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #2002-0131-2898
Fort Collins Police Services
Fort Collins, Colorado

March 2003

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Randy L. Tubbs of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS) and William J. Murphy of the Hearing Loss Prevention Section (HLPS), Division of Applied Research and Technology (DART). Field assistance was provided by Carol Goetz and Patricia Lovell, Certified Occupational Hearing Conservationists of HETAB, and Mark Little, Audiologist of HLPS. Desktop publishing was performed by Ellen Blythe of HETAB. Review and preparation for printing were performed by Penny Arthur.

Copies of this report have been sent to employee and management representatives at the Fort Collins Police Services. This report is not copyrighted and may be freely reproduced. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your written request to:

NIOSH Publications Office
4676 Columbia Parkway
Cincinnati, Ohio 45226
800-356-4674

After this time, copies may be purchased from the National Technical Information Service (NTIS) at 5825 Port Royal Road, Springfield, Virginia 22161. Information regarding the NTIS stock number may be obtained from the NIOSH Publications Office at the Cincinnati address.

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Weapon Noise and its Effects on Hearing of Police Officers

NIOSH investigators were requested to evaluate the customized hearing protectors used by the SWAT team during training exercises. We used temporary changes in hearing following weapons firing on the indoor and outdoor ranges as an estimate of noise overexposure. We also made thorough measurements of the noise from the weapons used by the department as well as measurements of the noise reduction from all the hearing protectors worn by the Fort Collins officers.

What NIOSH Did

- We tested the hearing of officers before and after firing their weapon on indoor and outdoor ranges.
- We measured the noise from all pistols, shotguns, and rifles used by the department.
- We use an artificial ear to evaluate the hearing protectors used by the officers on the firing ranges.
- We handed out a questionnaire to employees about their work history and self evaluation of their hearing.

What NIOSH Found

- Officers did not show poorer hearing following shooting.
- Most officers have normal hearing patterns.
- Weapon noise was found to be between 159 and 169 dB peak which is greater than a 140 dB peak exposure guideline from NIOSH.
- Radio transmissions were not incorporated into the customized protectors used by the SWAT officers.
- The hearing protection devices lowered noise about 30 dB peak. Double protection (plugs plus muffs) added 15-20 dB peak protection.

What Fort Collins Police Service Managers Can Do

- The department should research new hearing protection devices that incorporate radio communications into the device and are still compatible with other protection devices such as helmets and glasses.
- The department should begin a hearing conservation program with annual hearing tests.

What the Fort Collins Police Service Officers Can Do

- Officers should wear hearing protection whenever they are at the firing ranges.

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for HETA Report #2002-0131-2898

Health Hazard Evaluation Report 2002-0131-2898
Fort Collins Police Services
Fort Collins, Colorado
March 2003

Randy L. Tubbs, Ph.D.
William J. Murphy, Ph.D.

SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) received an employee request for a health hazard evaluation of the Fort Collins Police Service in Fort Collins, Colorado, in January 2002. The department was concerned about noise exposures and potential hearing damage from weapons training on their indoor and outdoor firing ranges. One specific concern was the Special Weapons And Tactics (SWAT) team of the Fort Collins Police Services and the type of customized hearing protection that they had recently purchased for the team members to use during training and deployment. To address these concerns, NIOSH conducted a temporary threshold shift (TTS) study of officers' hearing following weapons firing on a standard qualification course on the indoor and outdoor firing ranges. NIOSH investigators also used an acoustic mannequin head to measure noise levels produced by all weapons used by this department. This allowed for the measurement of noise levels when different hearing protection devices were placed on the mannequin, simulating the noise from weapons on protected and unprotected ears.

The hearing test results showed almost no temporary loss of hearing among officers following weapons firing for the qualification course used in the evaluation. Also, the pre-exposure hearing tests revealed normal hearing patterns for the majority of the department, with only the oldest group of officers (> 45 years) showing a mild hearing loss pattern at the higher test frequencies. The noise measurements for the various weapons ranged from 159-169 decibels (dB) peak which is greater than a 140 dB peak exposure guideline from NIOSH. The peak reductions afforded by the ear plugs, ear muffs, and customized SWAT team hearing protectors were all in the 30 dB range. Double hearing protection (plugs plus muffs) added 15–20 db more of peak reduction.

Based on the measurements and observations made during the evaluation, NIOSH investigators determined that a potential health hazard does exist for officers of the Fort Collins Police Service because the noise levels produced by their weapons are sufficient to put them at risk for occupational hearing loss. However, the hearing protection used by these officers does seem to offer protection as evidenced by the lack of TTS following a qualification course with pistols, shotguns, and rifles and by the normal hearing thresholds measured in nearly all of the officers.

Keywords: SIC 9221 (Police Protection), noise, weapons, firing range, hearing protection devices, audiometry, hearing loss, temporary threshold shift, TTS, noise spectra

Table of Contents

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received an employee request for a health hazard evaluation (HHE) from employees and management of the Fort Collins Police Services in Fort Collins, Colorado, in January 2002. The department was concerned about noise exposures and potential hearing damage from weapons training on their indoor and outdoor firing ranges. One specific concern was the Special Weapons And Tactics (SWAT) team of the Fort Collins Police Services and the adequacy of customized hearing protection that they had recently purchased for the team members to use during training and deployment.

NIOSH investigators spent the week of May 12, 2002, with the Fort Collins Police to test the hearing ability of several members of their department along with officers from other area law enforcement agencies and to measure the sound spectra for various weapons they use. Hearing tests were administered at the indoor firing range on Monday, Tuesday, and Friday and at the outdoor range on Wednesday and Thursday. Noise measurements were collected on the indoor range on Wednesday and on the outdoor range on Thursday. Individual hearing test results were sent to each participant along with an explanation of the audiogram in July 2002. For those who specified on the informed consent sheet, the same results package was sent to their designated physician or audiologist.

BACKGROUND

The Fort Collins Police Services patrols nearly 47 square miles in the city of Fort Collins, Colorado, which has an estimated population of 118,652. There are 148 sworn police officers in the department, which includes a 21-member SWAT team. In 2000, the department investigated 128,684 police incidents.

Each SWAT team member was issued a .223 caliber, short-barreled rifle for use in SWAT deployments approximately 2–3 years ago. They are also exposed to many different explosive devices used in training exercises and actual incidents. Their training schedule calls for monthly activities with weapons and explosive devices. A SWAT team from a nearby law enforcement agency had reported an incident where weapons similar to those used by the Fort Collins Police Services were fired inside an enclosed space during a deployment and team members suffered permanent hearing losses. This led the Fort Collins SWAT team to purchase specialized hearing protection devices (HPDs) for use in training exercises and in SWAT team deployments—Electronic Shooters Protection (ESP) Elite devices. The company's literature describes these devices as custom earmolds with analog electronics that amplify sounds under 90 decibels (dB), but damaging sounds above 90 dB are limited to safe levels by miniaturized compression circuitry. Two models of the devices were issued to the officers, a completely in the ear mold and a behind the ear model with three sizes of ear buds. These devices offered hearing protection in high noise conditions and amplification of signals in low noise situations, and they allowed the officers to wear helmets and goggles without interference as would be the case if ear muffs, for example, were used.

The regular training schedule and the high-powered weapons and explosive devices used with the electronic HPDs was an area of concern for members of the SWAT team. They wanted some assurance that the HPDs would protect them from permanent hearing loss resulting from the use of weapons and explosives in training and actual field situations. A temporary threshold shift (TTS) study was designed to investigate the risk of hearing damage from the SWAT team noise exposure situations. The TTS approach would not only identify any change in hearing following weapons' exposure, it would also document current levels of hearing. In addition to the TTS investigation, measurements of the noise signature from the weapons used by the Fort Collins Police

Services were made on the indoor and outdoor firing ranges. Simultaneous measurements of the protection offered by various HPDs and the levels produced by the weapons were collected with an acoustic mannequin as part of the evaluation.

TTS is a transient loss of hearing exhibited after exposure to brief, intense noise that dissipates over a short period of time. The parameters of TTS have been investigated by many researchers.[1] It has been consistently observed that higher frequency hearing (2–6 kilohertz [KHz]) is more easily affected by noise exposures than lower frequency.[2,3] The results from many experimental studies indicate that TTS recovers at a rate of 3 dB per doubling of recovery time.[4] The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council used the TTS index of 2 minutes (TTS_2) following the termination of a noise exposure in its attempt to derive damage-risk contours for noise.[5,6]

METHODS

TTS and Hearing Loss

All patrol officers of the Fort Collins Police Service were eligible for the hearing tests. Also, other local law enforcement officers from the Sheriff's Department and other local departments were invited to participate in the NIOSH investigation by the officer in charge of Fort Collin's SWAT operations. Officers reported to either the indoor or outdoor firing range when they were available during their work shift. Informed consent was obtained from each participant before a short questionnaire about work history and self-assessment of their hearing ability was given to them for completion. Audiometric tests were administered to each of the participants prior to the use of their weapon on the range. While on the range, the officer was instructed by the range officer to fire a standardized qualification course for the weapon being used. The three courses chosen by the Fort Collins Police Services were (1) qualification pistol - 1 which fires 24 rounds, (2) qualification shotgun - X which fires 12 rounds, and (3) Phase 1 of the SWAT operations standard drill for a 2 shooter-contact team which fires 20 rounds. The first two courses were used on the indoor range and the third course was used on the outdoor range. The pistol and shotgun qualification course were usually completed with two shooters on the indoor range, however, a few times only one shooter was available. As the outdoor qualification course states, two shooters were always present. Immediately upon completion of the qualification course, a stopwatch was started and the officer was escorted back to the audiometric test booth for a post-exposure hearing test. The time at which the left ear and right ear tests were finished was recorded on the person's questionnaire. The amount of TTS was calculated by subtracting the pre-qualification test from the post-qualification test resulting in a positive value if the officer's hearing got worse and a negative number if it got better.

Two Tracor Instruments (Austin, Texas) Model AR-200EC Audiometric Booths provided an acoustic environment for hearing testing. The booths were set up in an adjacent classroom at the indoor firing range and in a storage shed at the outdoor range. Conversations and other extraneous noises were controlled during testing. The booths were moved from the indoor to the outdoor range on Wednesday morning and returned to the indoor range on Friday for the last day of testing. Since electrical power was not available at the outdoor location, an electrical generator on the department's SWAT vehicle provided power to the shed. It was parked more than 100 yards from the storage shed with electrical extension cords running from the generator so that there was no noise impact on the test environment. Hearing tests were collected with Tremetrics (Eden Prairie, Minnesota) Model RA500 Audiometers that had received an exhaustive calibration check within the past year. Hearing tests were conducted by technicians who have current certification from the Council for Accreditation in Occupational Hearing Conservation (CAOHC). For the pre-weapons qualification test, the audiometer tested the pure-one frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hertz (Hz) in the computerized mode in each ear, left ear first. The post-qualification hearing test only used the frequencies of 2000, 3000, 4000, and 6000 Hz, the frequencies most sensitive to noise exposure, to reduce the time necessary to collect all of the data. These frequencies were also tested in the computerized mode.

Noise Measurements

Equipment and Calibration

Acoustic recordings of the gunshots were collected for both the indoor and outdoor firing ranges. Recordings were made using a Tascam DA-P1 Digital Audio Tape (DAT) recorder that digitized the microphone signals at 48000 samples per second. An external microphone and mannequin were positioned one meter to the left of the shooter. The mannequin was built by the French German Research Institute de Saint Louis (ISL) specifically for measuring impact and impulse noise.[7] The mannequin consists of the head, acoustic pinnae, and ear canals, Brüel and Kjær 4157 middle ear simulator, and a Brüel and Kjær 4165 ½-inch microphone. The maximum peak sound pressure level (SPL) that could be measured with the mannequin was 148 dB (dB SPL re 20 micropascals [µPa]). Since all of the mannequin measurements were performed under hearing protection, the maximum SPL was not exceeded. The sound outside the hearing protector was sampled by a Brüel and Kjær 4136 ¼ inch microphone which had a maximum sound pressure of 172 dB, sound pressure level (dB SPL). The 4136 microphone was positioned 6 centimeters from the right side of the mannequin head with the microphone pointed vertically upwards and was not touching the stand that supported the mannequin. The diaphragm of the microphone was visually aligned with the axis of the ear canal of the mannequin. The height of both the mannequin's ear canal and external microphone were adjusted to the same height as the shooter, 6 feet 2 inches, so that they were in the same plane as the shooter's ear canal.

Both the mannequin microphone and the external microphone were calibrated with a Brüel and Kjær 4228 piston-phone that produces a 124 dB SPL tone at 250 Hz. With the piston-phone running, the recording levels for the right (mannequin) and left (4136 microphone) channels of the DAT were adjusted to approximately 50 dB below the expected maximum signal levels, 150 and 170 dB SPL, respectively. Because the DAT recordings had to be transferred to computer for post hoc analysis, the recording settings were approximate and recordings of the calibration tones were collected at the beginning and end of each day's measurements. The calibration tone recordings were used to normalize the digital voltage levels into Pascals for the data analysis.

Weapons and Protectors

In Table 1, the 10 weapons that were tested with hearing protectors are listed. The weapons were a representative cross section of those used by the Fort Collins police officers. Specifically, the calibers were selected and then long and short-barreled models were chosen to address a concern that short-barreled weapons produced louder impulses than long-barreled weapons. In addition to the weapons in Table 1, measurements were collected for a group of 10 SWAT officers using Heckler and Koch (H&K) 53 and H&K 36 assault rifles. The H&K weapons used a .223 caliber frangible bullet. The expense of frangible ammunition prohibited the comprehensive measurements with hearing protectors at the indoor range. At the outdoor range, seven weapons were tested with hearing protectors and are listed in Table 2. Only the long-barreled models of the pistols were measured. Although the H&K 53 had a fully-automatic setting, the weapon was used with the single-shot setting.

Several types of hearing protectors were tested at both firing ranges. The protectors that will be discussed in this report are the David Clark Company (Worcester, Massachusetts) Model 27 earmuffs, Electronic Shooters Protection (ESP; Brighton, Colorado) Elite, and the Aearo™ Corporation (Indianapolis, Indiana) EAR® Classic® earplugs. Other protectors were measured for the purpose of developing a reference database of the impulse response of the protectors when measured on the ISL mannequin. For the David Clark earmuffs, three conditions were measured: earmuff alone, earmuff plus EAR Classic earplug together, and earmuff with safety glasses producing a leak under the earmuff cushion. The ESP Elite was essentially an in-the-ear assistive listening device with a wide spectrum gain function and compression circuit to limit the output of the device to nominally 90 dB SPL in a 2 cubic centimeter (cm^3) coupler. The ESP Elite did not have a Noise Reduction Rating (NRR) as required by the U.S. Environmental Protection Agency (EPA) for all hearing protection sold in the United States.[8]

Prior to the HHE, NIOSH researchers had Electronic Shooter Protection manufacture an ESP Elite protector for the ISL mannequin. The ESP device had approximately 3 millimeters between the end of the device in the ear canal and the grid for the ear simulator. The ESP device was tested at three gain settings: off, unity, and maximum. The unity gain was determined by performing a loudness match between the ESP and air-conducted sound in a double-walled sound room in the NIOSH Taft Laboratories. Three NIOSH researchers judged the unity output of the device and the mean setting was marked on the face of the device.

For each weapon, five shots were fired for each hearing protector condition. The shots were spaced approximately 2 seconds apart. Each protector condition was announced at the beginning of the recording. The weapons were announced to the external microphone before firing and were always tested in the order presented in Tables 1 and 2. The recording was stopped after each set of weapons. The recording times and any misfires or weapon malfunctions were recorded in a lab notebook.

Data Processing and Analysis

The DAT tape recordings were digitally transferred to .wav files using a Lexicon Core32 sound card. Each set of recordings were separated into a .wav file and directory. Next, the five-shot groups were isolated and saved as .wav files for analysis. The calibration tones were edited to select only the final portions of each channel's sample of the calibration signal. The calibration levels were calculated for each microphone and used in the subsequent analysis.

A Matlab program was developed to examine the average signal level as a function of time, permitting the researcher to identify the beginning of each gunshot within the sample. Once the start of each gunshot was identified, a time window of 42.67 or 170.67 milliseconds (ms) was analyzed for the peak protected and unprotected noise levels, the third-octave band spectra and the attenuation spectrum of the hearing protector. The shorter time window, 42.67 ms, was used with the outdoor measurements. The protected and unprotected equivalent levels, dB L_{eq}, were determined for linear weighting. The one third-octave unprotected spectra from each weapon were averaged across recordings to estimate the mean spectra for each weapon.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[9] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[10] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[11] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

Noise

The A-weighted decibel [dB(A)] is the preferred unit for measuring sound levels to assess worker noise exposures. The dB(A) scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 µPa, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dB(A) scale is logarithmic, increases of 3 dB(A), 10 dB(A), and 20 dB(A) represent a doubling, 10-fold increase, and 100-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in dBs cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise (29 CFR 1910.95)[11] specifies a maximum PEL of 90 dB(A) for a duration of 8 hours per day, expressed as a time-weighted average (TWA). The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dB(A) for no more than 4 hours, to 100 dB(A) for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dB(A) is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

$$\text{Dose} = 100 \text{ X } (C_1/T_1 + C_2/T_2 + ... + C_n/T_n),$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional action level (AL) of 85 dB(A); an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o). Finally, the OSHA noise standard states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels.

NIOSH, in its Criteria for a Recommended Standard,[12] and the ACGIH,[10] propose exposure criteria of 85 dB(A) as a TWA for 8 hours, 5 dB less than the OSHA standard. The criteria also use a more conservative 3 dB time/intensity trading relationship in calculating exposure limits. Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to no more than 88 dB(A) for 4 hours or 91 dB(A) for 2 hours. Twelve hours exposures have to be 83 dB(A) or less according to the NIOSH REL.

Noise-Induced Hearing Loss

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Initially, the noise exposure may cause a TTS, that is, a decrease in hearing sensitivity that typically returns to its former level within a few minutes to a few hours. Repeated exposures can lead to a permanent threshold shift. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically.[13] While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components.[14]

Audiometric evaluations of workers are conducted in quiet locations, preferably in a sound-attenuating chamber, by presenting pure tones of varying frequencies at threshold levels, i.e., the level of a sound that the person can just barely hear. Audiograms are displayed and stored as tables or charts of the hearing levels (HL) at specified test frequencies.[15] Zero dB HL represents the hearing level of the average, normal hearing individual. In OSHA-mandated hearing conservation programs, thresholds must be measured for pure-tone signals at the test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 Hz. Individual employee's annual audiograms are compared to their baseline audiogram to determine the amount of standard threshold shift (STS) that might have occurred over the time period being evaluated. Specifically, OSHA states that an STS has occurred if the average threshold values at 2000, 3000, and 4000 Hz have increased by 10 dB or more in either ear when comparing the annual audiogram to baseline audiogram.[11] The NIOSH recommended threshold shift criterion is a 15-dB shift at any frequency in either ear from 500–6000 Hz measured twice in succession.[12] Practically, the criterion is met by immediately retesting an employee who exhibits a 15-dB shift from baseline on an annual test. If the 15-dB shift is persistent on the second test, a confirmatory followup test should be given within 30 days of the initial annual examination. Both of these threshold shift criteria require at least two audiometric tests. In cases where only one audiogram is available, a criterion has been proposed for single-frequency impairment determinations.[16] It employs a lower fence (the amount of HL necessary before a hearing handicap is said to exist) of 25 dB. With this criterion, any person who has a hearing level of 26 dB HL or greater at any single frequency is classified as having some degree of hearing loss. The degree of loss can range from mild (26–40 dB HL) to profound (>90 dB HL).

Results

TTS and Hearing Loss

A total of 93 hearing tests were given over the five days of the site visit. Of this total, 71 tests were given to Fort Collins Police Services officers, 18 tests were given to officers of neighboring departments, and 4 tests were repeats for SWAT officers who were tested on Monday on the indoor range and on Wednesday at the outdoor range. The hearing test results figures include only the Fort Collins' officers; the other officers' data are included in the table listing the TTS values found following the firing of the various weapons. On the indoor range, participants fired either their service revolver or a 12-gauge shotgun. On the outdoor range, .223 caliber rifles were used. Hearing protection devices used on the indoor range were generally David Clark Model 27 earmuffs or custom-molded earplugs. For the 20 Fort Collins Police Services SWAT officers tested on the outdoor range, all but 4 wore the ESP Elite (14) or the behind-the-ear model Pro-Elite (2) custom-molded electronic devices. The other four wore EAR Classic earplugs (3) or EAR plugs plus Aearo Peltor® Model Tactical™ 7 earmuffs (1).

The mean hearing test results for the Fort Collins Police Services' officers who participated in the evaluation are shown in Figure 1. The graph shows the mean hearing levels for all 71 officers from the audiograms obtained before any weapons were fired by the officer. The left ear results are slightly poorer at the higher test frequencies, but overall, the mean results fall into a normal (<25 dB HL) hearing range for both ears. Sixty-three of the seventy-one officers were male. The mean age for the group is 37.2 years (range = 29–52 years). These officers have been in law enforcement for a mean of 12.9 years with a mean time of 10.4 years with the Fort Collins Police Services. The results were separated into age brackets to see the hearing profile trends over time, and are shown in Figure 2 for the left ear and Figure 3 for the right ear. These data show that all age groups of less than 46 years of age have mean levels that are in a normal hearing range for both ears. It is only the oldest group of officers that have mean hearing loss as a group in the higher test frequencies, 4000 Hz and above. The high frequency loss is classified as a mild loss.[16] When the SWAT officers are compared to the rest of the department, there is little difference between the two groups in their mean hearing levels (Figure 4). The mean age of the SWAT officers is 36.6 years with a mean time as an officer of 10.5 years. The remainder of the Fort Collins Polices Services have a mean age of 38.4 years and time in service of 13.8 years.

As previously noted, after completing the first audiometric examination, the officers were moved to the firing range and were instructed to fire their weapon using a standard firearm qualification course under the direction of the range instructor. Under most circumstances, two officers completed the course simultaneously in two adjacent lanes on the firing range. Immediately after completion of the qualification course, a stopwatch was started and the officers were quickly returned to the audiometric test booth for the modified audiometric examination of high-frequency pure tones. Elapsed times were recorded when the left ear test and right ear test were completed. TTS values were determined by subtracting the pre-qualification hearing test from the post-qualification test for each frequency tested.

The mean TTS values for each weapon type (pistol, rifle, or shotgun) and for the SWAT custom-made hearing protector are given in Table 3. The majority of the mean TTS values are negative numbers, meaning that the officers actually heard better following the qualification course on the firing range. Mean completion times on the indoor range for the left ear tests were slightly greater than 2 minutes and the right ears were finished in 3.25 minutes. On the outdoor range the officers were tested further away from the firing line and it took nearly 3.5 minutes to finish the left ears and 4.5 minutes to finish the right ears. The mean TTS values for SWAT officers wearing the ESP hearing protectors and firing .223 cal rifles were less than 1.0 dB, with the majority being 0.0 dB or less. Inspection of individual results shows only one instance where the change in hearing was +10 dB at a test frequency of 6000 Hz. When the three types of weapons used by the officers are looked at separately, the mean TTS values are all less than 1.0 dB. For the .223 cal rifle used on the outdoor range, there were two individuals out of 26 tested that had TTS values of +10 dB, one at 4000 Hz and the other at 6000 Hz. On the indoor range, the pistol qualification course resulted in 11 of 52 officers exhibiting a TTS of +10 dB or greater. Two of the 11 officers had +10 dB shifts at two separate test frequencies. Ten of the shifts occurred at the 6000 Hz test frequency. The shotgun qualification course resulted in only one officer out of 14 that had a +10 dB shift at 4000 Hz. No individual TTS exceeded +20 dB.

Noise Measurements

Peak Exposure Levels

Figure 5 shows the mannequin's protected ear and the unprotected waveforms for a Smith & Wesson revolver recorded at the outdoor firing range. The measurements at the outdoor range provided a better approximation to what one might expect in an anechoic environment, one with fewer reflected sound waves. Particularly, the first impulse of the shockwave from the muzzle of the weapon was extracted for analysis. The recording conditions (drizzling rain) required that we use a fabric tent over the shooting area. The ground, ISL mannequin, tent, shooter, shooter's assistant, picnic table, and weapons were potential reflective surfaces. Of these, the side of the mannequin's head reflected the most energy (see the double peak at 1.82 ms). Peaks at 3.58 and 4.23 ms probably correspond to reflections from the tent and the shooter. The peak at 6.24 ms is consistent with the path length difference between the direct and ground-reflected paths.

The protected waveform (solid blue line) for the Smith & Wesson 586 and David Clark Model 27 earmuffs yielded a peak protected level of 137.5 dB SPL. The waveform was less sharply peaked than the unprotected waveform (solid red line). This difference was primarily a function of the hearing protector. Earmuffs generally yielded a low-pass filter that smoothed the jagged nature of the waveform. Earplugs, such as the EAR Classic, had more low frequency attenuation than the earmuff. Consequently, the resulting protected waveforms were not dominated by the low-frequency signal and more closely resembled the unprotected waveform.

Figure 6 shows a pair of bar graphs indicating the average and standard deviation of the maximum peak sound pressure level in decibels referenced to 20 μPa measured at the indoor and outdoor firing ranges. For the indoor range (upper panel), the Smith & Wesson 586 and 686 revolvers had sound pressures of 167.9 and 167.1 dB SPL, respectively. The Colt Pocket9 and Par-Ordinance P10 pistols had the next greatest peak pressures of 162.3 and 162.4 dB SPL, respectively. The remaining weapons at the indoor range had peak pressures that ranged from 158.6 to 160.8 dB SPL. For the outdoor range (lower panel), the Smith & Wesson 586 revolver and the H & K 53 rifle had the highest peak pressures of 168.6 and 166.8 dB SPL, respectively. The other weapons ranged from 159.0 to 161.5 dB SPL.

Weapons Spectra

In Figure 7, the ⅓-octave band spectra of the weapons tested on the outdoor range are displayed in staircase plots. The horizontal lines are spaced in 10 decibel intervals and the dark bar at the center of each spectrum is the 1000 Hz band. For most of the weapons, the maximum level is between 500 and 800 Hz. With the exception of the Glock 22 and Colt 1991-A1, the maximum band exceeded 130 dB SPL. The maximum energy of the Smith & Wesson 586 was at 2000 Hz.

One point should be clarified about the ⅓-octave band analysis. The estimate of the peak impulse level is based upon the instantaneous sound pressure. The third-octave analysis represents the average of the signal over the analysis window (42.67 ms for the outdoor data). One may visualize spreading the instantaneous peak over the analysis window. If a single gunshot is sampled with both a short and long time window, the long-window third-octave analysis will yield lower estimates of the band levels. For this reason, the peak sound pressure levels are listed on the weapon spectra in Figure 7 rather than the logarithmic sum of the ⅓-octave bands.

Spectral Difference Plots

To better examine the differences between weapons, the .450 caliber Colt 1991 A1 pistol was used as a reference spectrum and was subtracted from the spectra of the other weapons shown in Figure 8. The spectra for the Glock 22, Sig Sauer P228 and Colt 1991-A1 were similar except at the high frequencies. The Colt AR-15 levels were approximately 7-10 dB/band greater below 200 Hz. From 400 to 1000 Hz, the AR-15 levels were 3-5 dB/band higher. The Remington 11-87 shotgun was greater by 5-14 dB/band below 400 Hz. Above 4000 Hz, the shotgun was slightly greater than the Colt 1991-A1. The Smith & Wesson 586 levels were 5-15 dB/band higher in almost every band. Above 250 Hz, the 586 was not more than 10 dB/band greater than the Colt 1991-A1. The peak level from the Smith & Wesson 586 in Figure 7 was also evident in the difference plot at 2000 Hz. The H & K 53 exhibited the greatest spectral differences at 20 of 27 third-octave band frequencies. Below 500 Hz, the H&K 53 exceeded the Colt 1991-A1 by 10-15 dB/band. Above 500 Hz, the H&K 53 was greater by about 5-10 dB/band.

David Clark Model 27 Earmuff Plus EAR Classic Earplug Attenuation

Figure 9 shows the attenuations measured for the David Clark Model 27 earmuff, EAR Classic earplug, and David Clark Model 27 with EAR Classic. The David Clark muffs exhibited attenuations of about 10 dB/band at 100 Hz and below. From 100-500 Hz, the attenuation increased to about 35 dB. The attenuation above 500 Hz varied between 28 and 40 dB/band. The Classic earplug increased in attenuation from 18 dB at 25 Hz to 38 dB at 800 Hz. Above 800 Hz, the attenuation ranged from 30 to 52 dB/band.

The combination of the David Clark and Classic protectors were measured at both firing ranges. The indoor range data below 250 Hz exhibited attenuations close to the sum of the David Clark and Classic measured separately. Above 250 Hz, the attenuations varied over a range of 40 decibels. The differences were likely due to resonances in transmission through the protectors and resonances of the enclosed volumes of the earmuff and earplug.

The results with David Clark Model 27 when worn with safety glasses are presented in Figure 10. Two features are prominent in the figure: the attenuation is negative below 200 Hz; the attenuation at 2000 Hz varies more than the adjacent frequencies. The variability at 2000 Hz correlates with the output of various weapons at that frequency. The low-pass filtering of the earmuff will yield greater exposure underneath the earmuffs for weapons with significant low-frequency content such as the H & K 53, Colt AR-15, Remington 11-87 and the Smith and Wesson 586.

Electronic Shooter Protection Elite

The ESP Elite was tested at both firing ranges for three gain settings—off, unity, and maximum gain. In Figure 11, the off setting is shown with gray symbols, unity with green, and maximum with red symbols. The outdoor attenuations are shown with squares and the indoor with circles. The indoor and outdoor attenuations differed considerably between 100 and 400 Hz. Above 2500 Hz, the outdoor and indoor attenuations differed by as much as 10 dBs. When the ESP Elite was turned off, the attenuations above 2500 Hz are within 4 dB for the indoor and outdoor measurements. The disparity between the indoor and outdoor results suggest that the ESP may be sensitive to how well it was fit in the mannequin ear canal.

In Figure 12, the summary analysis of 24 ESP Elite protectors performed with the Frye FP40 Hearing Aid Analyzer is shown.[17] In the upper panel, the histogram of the maximum SPL output of the ESP exhibited a wide range of levels from 90 to 105 dB SPL. In the lower panel, the histogram of the average of the saturated SPL determined as the average of 1000, 1600 and 2500 Hz is shown. The upper histogram seems to have two groups centered at 92 and 102 dBs. The lower histogram is centered about 88 dB and has one group.

The data from Figure 12 suggest that officers wearing the ESP Elite could be exposed to levels of noise above the NIOSH recommended limit of 85 dB if they use the maximum gain. The ESP Elite measured on the mannequin exhibited more attenuation at the low frequencies and comparable attenuation at the high frequencies when compared to the David Clark Model 27 earmuffs. While the measured peak impulse levels of gunshots underneath the ESP were approximately 128 to 138 dB, the highest saturated sound pressure output of the ESP device was limited to about 105 dB (the average of 1000, 1600 and 2500 Hz with a 90 dB input). The exposure to the weapon posed the greatest risk of noise exposure.
The averages of the peak reduction are shown in Figure 13 for the various hearing protector, safety glasses, and range conditions. The earmuffs with safety glasses had a reduction of 12 and 18 dBs. The earmuffs alone reduced the peak energy by 29 and 32 dB. The peak energy reduction of the EAR Classic was 29 dB. The peak reductions for the combined earmuff and earplug were 46 and 50 dB. The peak reductions for the ESP Elite protector were approximately 30-31 decibels regardless of the volume setting.

Discussion

TTS and Hearing Loss

The weapon qualification courses fired by the officers did not result in significant amounts of TTS. The mean values were consistently less than 0 dB, meaning that the HPDs used during this evaluation seems to have prevented temporary changes in hearing for the officers firing their weapons under these circumstances. These data are somewhat different from previously presented results of TTS in officers who wore double hearing protection on an indoor firing range and were found to exhibit an average TTS of 9 dB at 6000 Hz when the ear plug was not properly inserted into their ears.[18] The pre-noise exposure audiometric examinations also showed that the average Fort Collins Police Service officer tested did not show hearing loss patterns consistent with noise over-exposures. Only the oldest group of officers (> 45 yrs.) had mean hearing levels that fell into a mild hearing loss category for the higher test frequencies (4000, 6000, and 8000 Hz). One finding in the hearing data, however, does raise some concern. For the individual officers tested who exhibited temporary shifts of 10 dB or more, nearly all of the changes were at 6000 Hz, the test frequency where the older officers were found to have mild hearing loss.

Noise Measurements

Peak Exposure Levels

Several issues need to be considered with respect to these data. First, the mannequin was designed to estimate the airborne transmission path for an external sound attenuated by a hearing protector. In the human, the acoustic energy can reach the cochlea through several pathways: through the air, through the hearing protection, through leaks around the hearing protection, through the oral-nasal cavities (transmitted into the middle ear cavities), and through bone conduction. The attenuations measured at the high frequencies with the mannequin are not representative of the attenuations measured using the real-ear attenuation at threshold method for humans subjects. The mannequin has more isolation of the microphone and thus does not recreate the bone-conduction and oral-nasal pathways. However, the peak level reductions may be reasonable estimates for what a human subject would experience.

Second, the attenuation of a protector used in impulsive noise may not be the same when used in continuous noise. Newton's first law of motion states, "*Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it*."[19] An acoustic shock wave will impart energy to the protector, but may not be as effective in causing the protector to oscillate or vibrate as a low-amplitude continuous waveform. Protector attenuations are tested using continuous third-octave band noise at or near the threshold of hearing. An impulsive waveform will excite the protector at effectively all frequencies, but the energy is transmitted over a short time period. If the device being excited behaves in a nonlinear manner, the transmission of a high-level impulse may be affected by the nonlinearity while the transmission of low-level continuous noise will not be affected. Acoustic nonlinearities become important at signal levels above 120 decibels. Acoustic shock waves can be formed at levels of 140 dB and greater when the impedance of the air becomes nonlinear. The attenuation for continuous noises remains constant as a function of level over a wide range of signal levels. The peak reduction data in Figure 13 were presented as bar graphs because the peak reduction was constant within the error limits over the range of weapons tested. The only device that was not constant was the earmuff with safety glasses. The safety glasses will be discussed in a later section of this report.

Third, the audiology, occupational safety and health, and military communities have not reached a consensus regarding the risk of hearing loss when it comes to impulse noise. Particularly, the U.S Military Standard 1474D yields estimates of the daily allowed number of rounds fired that seem to be unacceptably high (one calculation using a protected waveform under an earmuff yielded 3000 shots for a Colt AR-15 rifle).[20] Other calculations suggest that 100 to 1000 shots is the recommended number of shots. NIOSH has proposed the following formula for evaluating the risk of impulsive noise,

$$N = 10^{(140 - \mathrm{PI\ dB})/10}$$

where N is the total number of shots and PI dB is the peak impulsive level in dB SPL.[21] Using this formula and the peak levels in Figure 6 and the peak reductions in Figure 13, the officers would be exposed to peak impulse levels of 130–140 dB SPL. Applying this formula yields an allowable number of shots of 1 to 10 shots per day. This proposed formula is a conservative estimate and makes no compensation for the duration of the impulse.[22,23,24] Applying the NIOSH formula to the double-protected data increases the allowable number of shots from 100 to 1000. Even though only a few of the officers experienced a small shift in this evaluation, properly-fit, double protection should minimize TTS and potential permanent threshold shifts.

David Clark Model 27 Earmuff Attenuation

The David Clark Model 27 earmuffs yielded peak reductions that are typical of other earmuffs measured with these methods.[25] A peak reduction of 30 decibels is typical of other earmuffs that were measured for 9mm and .223 caliber weapons. Two areas of concern should be addressed with the earmuff usage by the Fort Collins Police Service SWAT officers: the use of HPDs with safety glasses; and the use of the devices with helmets.

During the HHE, the mannequin measurements were performed with and without safety glasses. As shown in Figure 13, the peak reductions were diminished when the safety glasses disrupted the seal of the earmuff cushion with the side of the head. The small opening around the earpiece of the glasses lowered the effective peak reduction by 20 to 30 dBs. Using the peak levels from Figure 6, the officer with a comparable leak could be exposed to 156 to 150 dB peak SPL. If the officers could wear the safety glasses over the top of the earmuff cushions, or use glasses with a strap or low profile stem rather than a high profile stem, the size of the leak could be reduced or eliminated. Ideally, the safety glasses should be an integral part of the earmuff or the helmet.

The peak level reduction for the earmuff with safety glasses exhibited a slight increase in peak reduction as the peak SPL increased. This effect is consistent with nonlinear acoustic impedance of shockwaves that impinge upon an orifice. In fact, nonlinear impedance forms the basis of several hearing protection devices, such as the EAR Combat-Arms earplug, Bilsom ISL earplug, and the EAR Ultra 9000 shooters earmuff.

The second issue is using earmuffs with the SWAT officers helmets. The officers had Kevlar helmets that had attachment points for face shields but not hearing protectors. Also, the helmets covered the upper half of the pinna. Consequently, the current helmet could not be used with the circumaural earmuffs used by the Fort Collins Police Service. However, Peltor now makes a hearing protection device that permits the use of a helmet with an earmuff (Peltor® COM-TAC and SWAT•TAC). There is also research being conducted for the U.S. military on the use of earplugs with communication capabilities for impulsive and steady-state noise environments.[26]

Performance of the ESP Elite Devices

The ESP Elite exhibited inconsistent attenuation within the measurements collected at both firing ranges, which may have been a function of how well the device was fit. At each location, the device was inserted fully into the mannequin's ear canal and pinna. The insertion is not difficult and should not have caused any effect between the two ranges. The data in the lower panel of Figure 12 suggests that the ESP device yields a consistent saturated SPL, the average of the output at 1000, 1600 and 2500 Hz in response to a 90 dB SPL input.

One of the issues which applies more to hearing aids and sound-restoration earmuffs is the performance in intermittent noise. Typically a device will use either a level-limiting, compression, or automatic gain control circuit to limit the maximum SPL output of the electronics. For lower SPL, these devices are able to amplify the sound and reproduce the signal at a level which is above the attenuated SPL and below its maximum output level. The output of the ESP Elite, or other electronic hearing protectors, in response to high amplitude impulsive sounds, will not be reproduced by these devices due to mechanical and electrical limitations. In other words, an intermittent peak of 80 dB might be attenuated by 20 dB resulting in an unaided/unamplified sound pressure level of 60 dB. When the device amplifies that sound by 20 dB, the output would be restored to the 80 dB level. For a high amplitude impulsive sound (160 dB), the device might attenuate by 20 dB, but the amplification cannot restore the sound level to 160 dB because it exceeds the capability of the circuitry. This shortcoming is good, because the device will not reproduce harmful sound pressure levels that exceed the capability of the circuitry. For intermittent noise, these devices also have some recovery time after a loud sound occurs. The recovery time can adversely affect communication by cutting of the speech during a loud sound. The manufacturer lists the release time as 400 ms. The hearing aid analyzer that was used in the field to assess the performance of the ESP Elite protectors was not equipped to measure the attack and release times. For an intermittent noise, a short recovery time might have less of an effect on communication.

Another issue that should be considered with the officers using the ESP device is how well the earpiece fits. Every officer using the ESP should have the fit of the device tested to determine whether they are achieving an effective seal of the ear canal. A poor seal could increase the noise exposure that officers receive. FitCheck is a product which can be installed on a personal computer running Windows software.[27] FitCheck measures the attenuation of earplugs using narrow-band noise signals. If an officer does not receive a reasonable amount of attenuation (15–30 decibels in every frequency band), the device should be remade. Unfortunately, the ESP Elite protector does not have an EPA NRR.[8] If it had an NRR, consumers would know what attenuation to expect if fit testing were performed.

Performance of the EAR Classic

The EAR Classic earplug yielded a peak level reduction of 30 dBs. Again this number seems to be typical for a well fit protector on the mannequin. The Classic earplug exhibits a consistent performance across subjects and is not as susceptible to acoustic leaks as other earplugs.[28] For a human, the Classic earplug can be inserted anywhere from 10 to 100 percent of the length of the earplug into the ear canal. With respect to real ear attenuation at threshold, the attenuation is affected by how much of the earplug has been inserted. For the ISL mannequin, a maximum of 60 percent of the earplug could be inserted into the ear canal. The peak reduction in a human ear canal may be more or less depending upon how much of the earplug is inserted. Real-world studies of hearing protector devices have shown that they do not achieve the manufacturer's measured attenuations for experimenter fit earplugs.[29,30]

CONCLUSIONS

Using the NIOSH REL as a guideline, the officers should not be exposed to noise impulses above 140 dB for any amount of time.[12] The unprotected peak noise levels measured on the acoustic mannequin were found to range from 159 to 169 dB. The results from the TTS study indicate that the weapons' noise is not great enough to result in a temporary loss of hearing while firing a single standard qualification course on either the indoor or outdoor range with the HPDs used during the evaluation. The baseline hearing tests for the police service revealed normal hearing patterns for all but the oldest group of officers. It is possible that the mild hearing loss measured in the oldest group is the result of different work practices used by the police service when these officers were just beginning their careers and that the current group of young officers will not necessarily accrue occupational hearing loss. Or these results may show that the amount of sound energy from their weapons is intense enough to eventually result in hearing loss. It is not possible to answer this question with the data collected during this evaluation.

The measurements of the protection afforded by the HPDs were consistently in the 30 dB range (Figure 13), unless the earmuff seal with the side of the mannequin was broken by the safety glasses.

These peak reduction results along with the peak noise levels measured for the weapons indicate that the officers should consider using dual hearing protection during weapons training exercises for maximum protection. To overcome the inability to communicate when double-protected, the officers should be provided with electronic level-limiting earmuffs and a choice of earplugs. The earplugs can provide an additional 15–20 dB of peak reduction while the electronic earmuffs can compensate for the reduced speech intelligibility due to double protection. If the protected peak SPL are in the 120–130 dB range, then the NIOSH formula suggests that 100 to 1000 shots per day would be allowed. Recognizing that this is a conservative estimate, officers will not be exposed to an excessive risk of hearing loss with double protection. In addition to the electronic earmuffs, commercially available communication headsets exist that would permit the range officer to transmit instructions via short range radio to the officer's headset that could improve the communication even further. Companies such as Aearo/Peltor, Baccou-Dalloz (Bilsom), David Clark, and Hellberg make combined hearing protector and communication systems that might be adaptable to the SWAT team's needs during training and during deployment.

Recommendations

Based on the measurements and observations made in the evaluation of weapon noise and its effect on hearing for the Fort Collins Police Service, the following recommendations are made to improve working conditions for the officers.

1. The use of double hearing protection is warrented during weapons training exercises. The peak noise levels measured for the weapons and the amount of attenuation given by the HPDs are such that double protection will offer maximum protection and some insurance against improper fitting of the devices or incompatibility with other personal protective equipment.

2. Although the ESP device worn by the SWAT officers did not result in any TTS, the Fort Collins Police Service should investigate other devices that are available. The ESP Elite does not have an NRR rating which is required by the EPA for HPDs.[8] The device also does not allow for closed-circuit radio communications which would limit the broadcasting of radio transmissions into an environment that may be better protected with radio silence. HPDs that offer this are beginning to be available. These devices should be reviewed to see if they are compatible with the SWAT team's equipment and practices.

3. The noise levels that are generated by the weapons used by the police service are intense enough to warrant the initiation of a hearing conservation program. As a minimum, the hearing conservation program should meet the requirements of the OSHA hearing conservation amendment (29 CFR 1910.95).[11] Other sources for defining effective hearing conservation programs are also available.[31,32,33]

References

1. Davis H, Morgan CT, Hawkins Jr. JE, Galambos R, Smith FN [1950]. Temporary deafness following exposure to loud tone and noise. Acta Otolaryngologica Supplement 88:1–57.

2. Hirsh IJ, Ward WD [1952]. Recovery of the auditory threshold after strong acoustic stimulation. Journal of the Acoustical Society of America 24:131–141.

3. Kryter KD [1963]. Exposure to steady-state noise and impairment of hearing. Journal of the Acoustical Society of America 35:1515–1525.

4. Kryter KD [1970]. The effects of noise on man. New York, NY: Academic Press.

5. Kryter KD, Ward WD, Miller JD, Eldredge DH [1966]. Hazardous exposure to intermittent and steady-state noise. Journal of the Acoustical Society of America 39:451–464.

6. Ward WD [1966]. The use of TTS in the derivation of damage risk criteria for noise exposure. International Audiology 5:309–313.

7. Franke R, Parmentier G, Buck K, Evrard G, Kronenberger G, Beck C, Brunner JJ [1994]. Tete artificielle pour l'evaluation de l'efficacite des protecteours auditifs vis a vis bruis de niveau eleve Partie 1: Developpement et essais en regime impulsionnel. Research report French-German Institute for Research of Saint Louis. Report R-112/94.

8. EPA [1978]. Noise labeling requirements for hearing protectors. Fed Regist 44(190), 40CFR part 211, 56130-56147.

9. NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. 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, DHHS (NIOSH) Publication No. 92-100.

10. ACGIH [2002]. 2002 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of

Governmental Industrial Hygienists.

11. CFR [1997]. 29 CFR 1910.1000. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

12. NIOSH [1998]. Criteria for a recommended standard: occupational noise exposure (revised criteria 1998). Cincinnati, OH: U.S. Department of Health and Human Services, U.S. Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126.

13. Ward WD, Royster LH, Royster JD [2000]. Anatomy & physiology of the ear: normal and damaged hearing. Chapter 4. In: Berger EH, Royster LH, Royster JD, Driscoll DP, & Layne M, eds. The noise manual. 5th ed. Fairfax, VA: American Industrial Hygiene Association, pp 101–122.

14. Suter AH [1978]. The ability of mildly hearing–impaired individuals to discriminate speech in noise. Washington, DC: U.S. Environmental Protection Agency, Joint EPA/USAF study, EPA 550/9–78–100, AMRL–TR–78–4.

15. ANSI [1996]. American national standard specification for audiometers. Melville, NY: Acoustical Society of America, American National Standards Institute, ANSI S3.6-1996.

16. Eagles EL, Hardy WG, Catlin FI [1968]. Human communication: The public health aspects of hearing, language, and speech disorders (NINDB monograph #7). Washington, DC: Government Printing Office, USPHS Publication 1745.

17. ANSI [1996]. American national standard of hearing aid characteristics. Melville, NY: Acoustical Society of America, American National Standards Institute, ANSI S3.22-1996.

18. Tubbs RL [1992]. Temporary threshold shifts in hearing following exposure to gunfire noise on firing ranges. Unpublished paper presented at the 27th Annual Meeting of the U.S. Public Health Service Professional Association, Cincinnati, Ohio, April 25–28.

19. Newton I [1686]. *Philosopiae Naturalis Principia Mathematica.*

20. MIL-STD-1474D [1997]. Department of defense design criteria standard: Noise limits, AMSC, A7245.

21. NIOSH [2002]. Comments of the National Institute for Occupational Safety and Health on the Occupational Safety and Health Administration ANPR Hearing Conservation Program for Construction Workers 29 CFR Part 1926 Docket No. H-011G. 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.

22. Smoorenburg GF [1982]. Damage risk criteria for impulse noise. In: Hamernik R, Henderson D, Savli R, eds. New perspectives on noise-induced hearing loss. New York, NY: Raven Press, pp 471–490.

23. Pfander F, Bongartz, H, Brinkman H, Kietz H [1980]. Danger of auditory impairment from impulse noise: A comparative study of the CHABA damage-risk criteria and those of the Federal Republic of Germany. Journal of the Acoustical Society of America 67:628–633.

24. Pfander F [1975]. Das Knalltrauma. Berlin, Heidelberg, New York: Springer Verlag.

25. Murphy WJ, Little MB [2002]. Performance of electroacoustic hearing protectors. Presented at the 143rd meeting of the Acoustical Society of America, Pittsburgh, PA, June 3, 2002.

26. Mozo B [2003]. Communications & Ear Protection, Inc. [http://www.cep-usa.com]. Date accessed: February 2003.

27. Michael KL [1998]. Comprehensive use of hearing protectors: Integration of training, field monitoring, communication and documentation. Journal of Occupational Hearing Loss 1:67–74.

28. Murphy WJ, Franks JR, Krieg EF [2002]. Hearing protector attenuation: Models of attenuation distributions. Journal of the Acoustical Society of America 111:2109–-2118.

29. NIOSH [1995]. The NIOSH compendium of hearing protection devices. 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, DHHS (NIOSH) Publication No. 95–105.

30. Berger EH, Franks JR, Behar A, Casali JG, Dixon-Ernst C, Kieper RW, Merry CJ, Mozo BT, Nixon CW, Ohlin D, Royster JD, Royster LH [1998]. Development of a new standard laboratory protocol for estimating the field attenuation of hearing protection devices. Part III. The validity of using subject-fit data. Journal of the Acoustical Society of America 103:665–-672.

31. NIOSH [1996]. Preventing occupational hearing loss–A practical guide. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 96–110.

32. Suter AH [2002]. Hearing conservation manual. 4th ed. Milwaukee, WI: Council for Accreditation in Occupational Hearing Conservation.

33. Royster JD, Royster LH [1990]. Hearing conservation programs: practical guidelines for success. Chelsea, MI: Lewis Publishers.

Figure 1
Hearing Levels - Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002

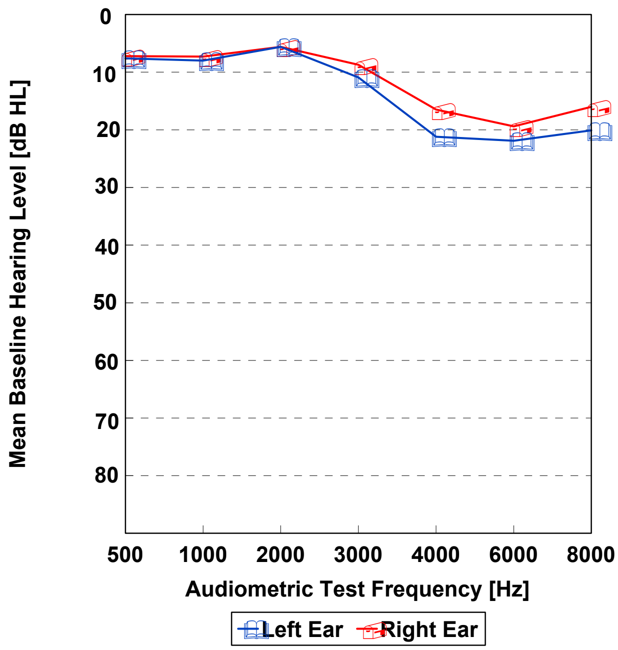


Figure 2
Left Ear Hearing Levels by Age
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002

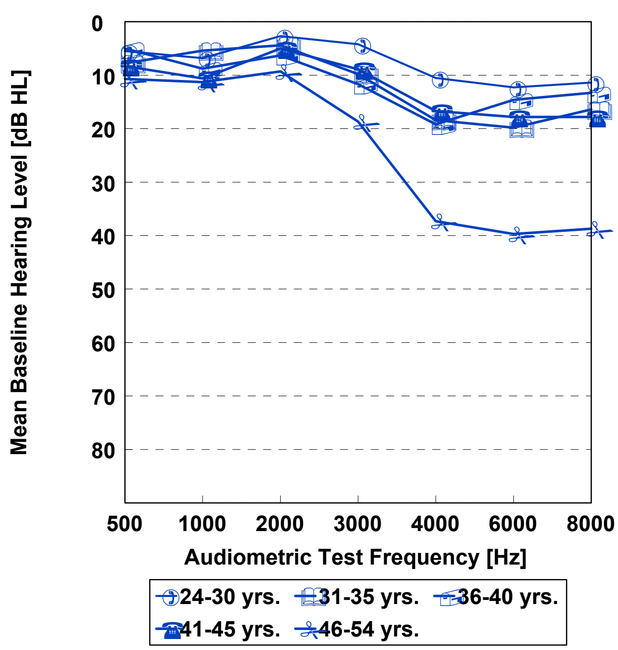


Figure 3
Right Ear Hearing Levels by Age
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002

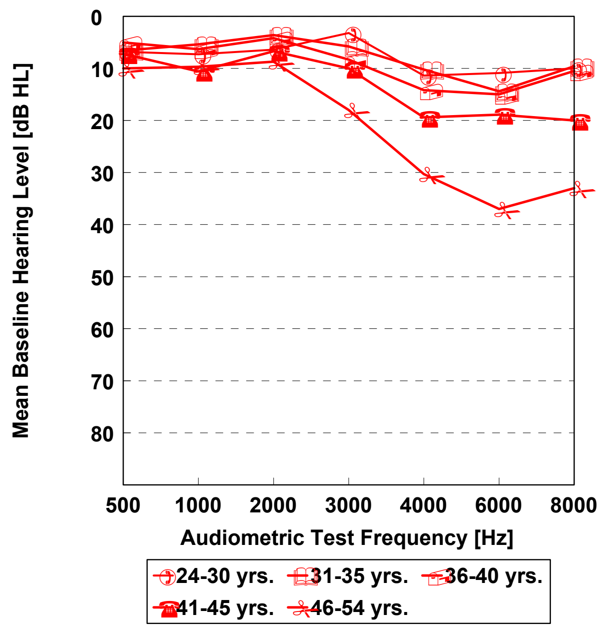


Figure 4
SWAT versus Rest of Department Hearing Levels
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002

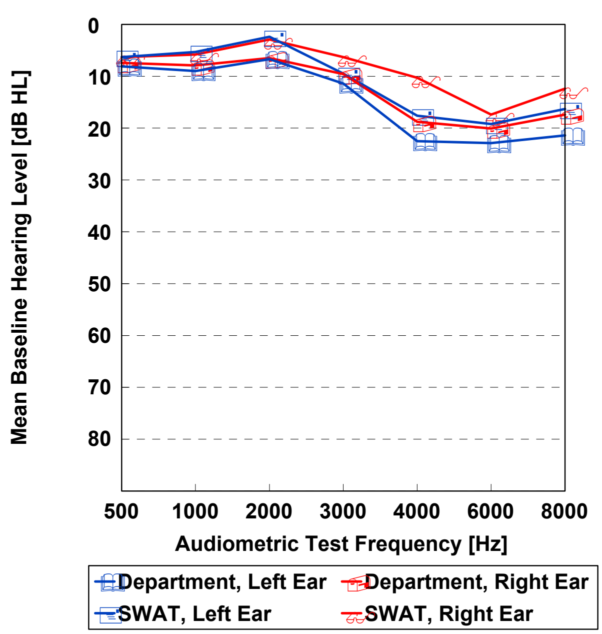
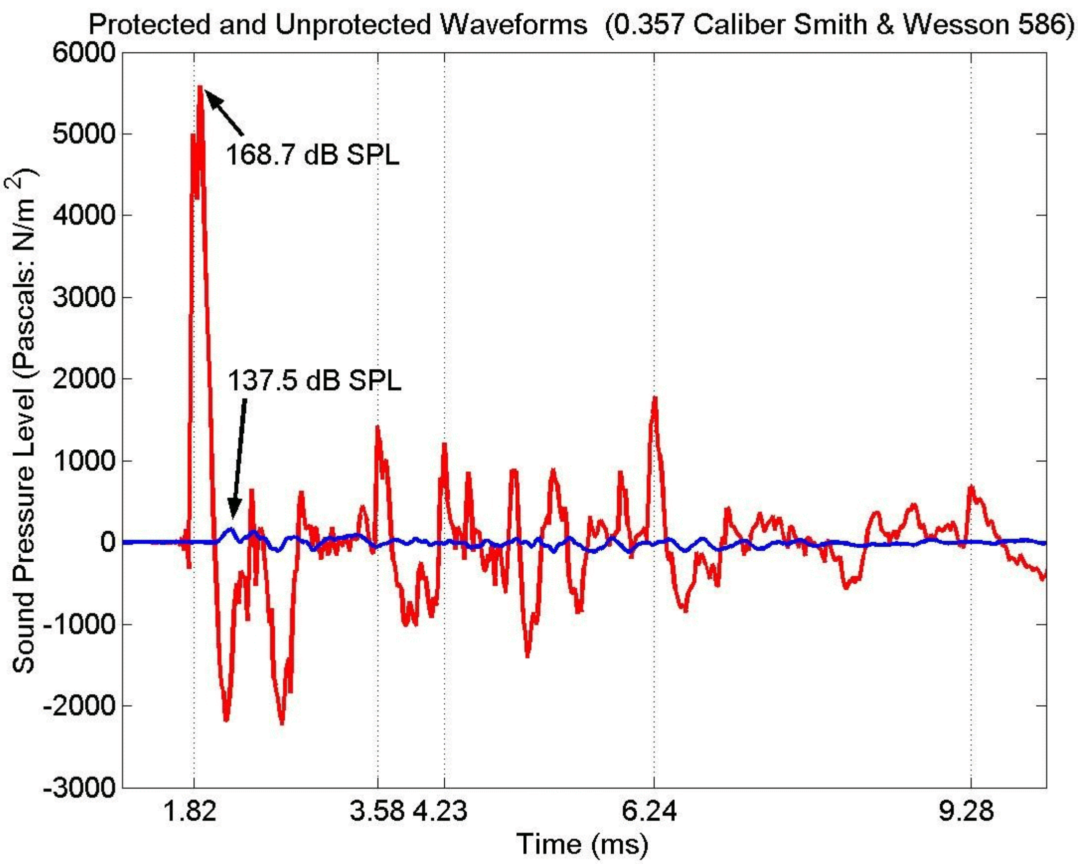


Figure 5
Outdoor Recording of the Unprotected and Protected Waveforms
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



Measurements from the Bruel & Kjaer 4136 microphone and ISL mannequin. The red line is the unprotected waveform (microphone) and the blue line is the protected (mannequin). The vertical dashed lines indicate the presence of reflected pressure waves from surrounding objects.

Figure 6
Peak impulse noise levels at the indoor and outdoor firing ranges
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002

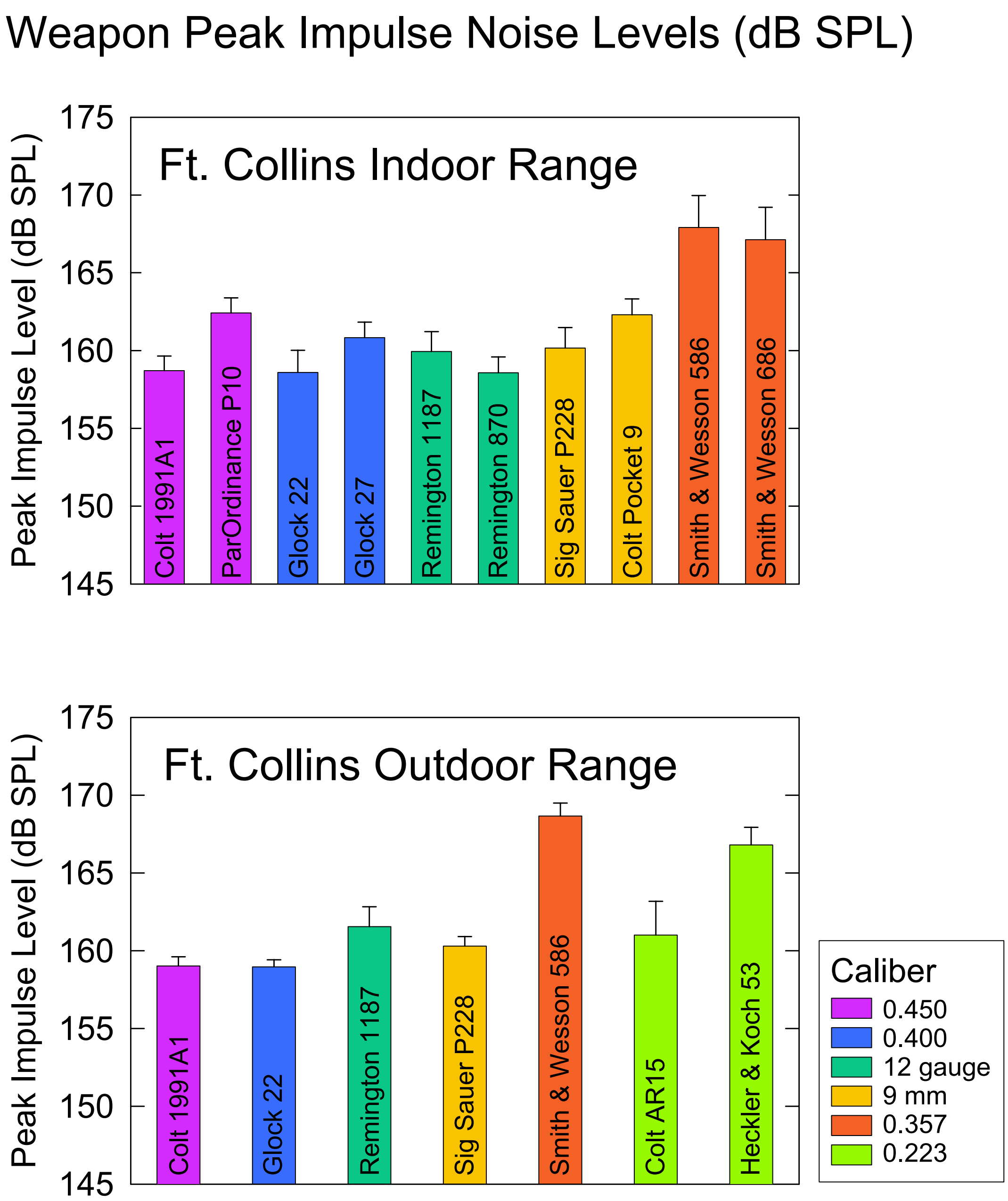
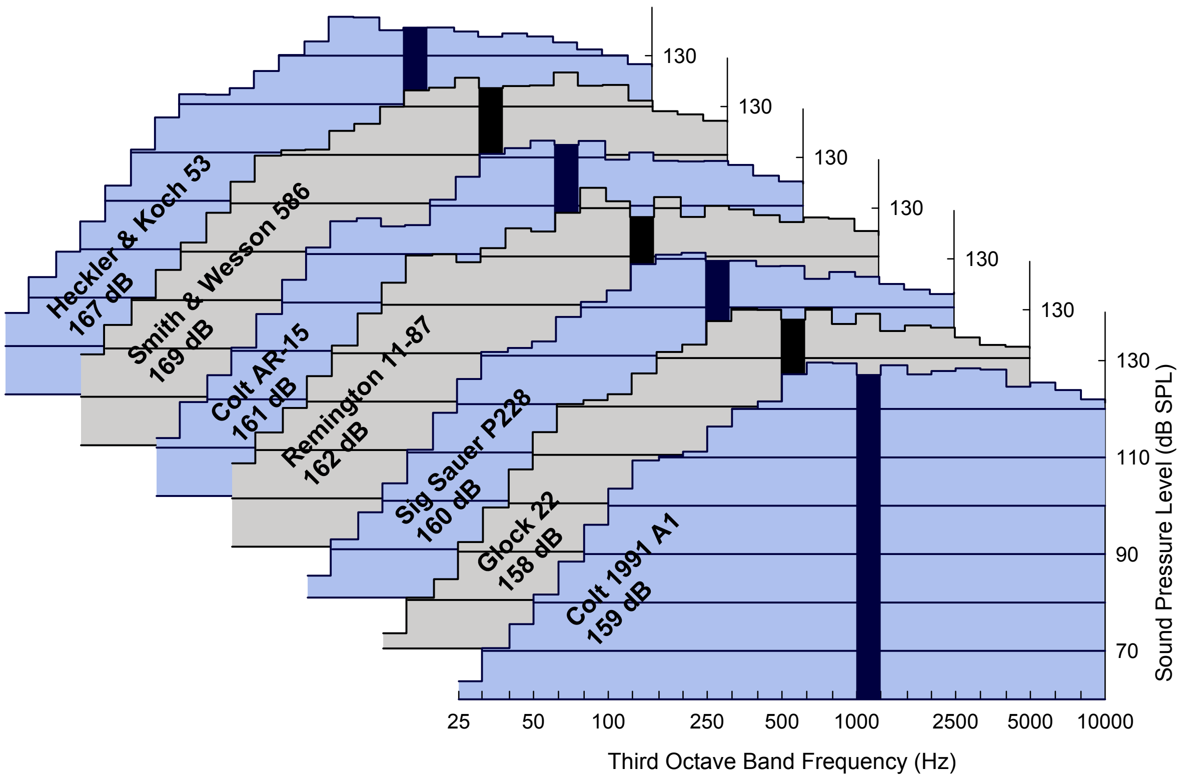
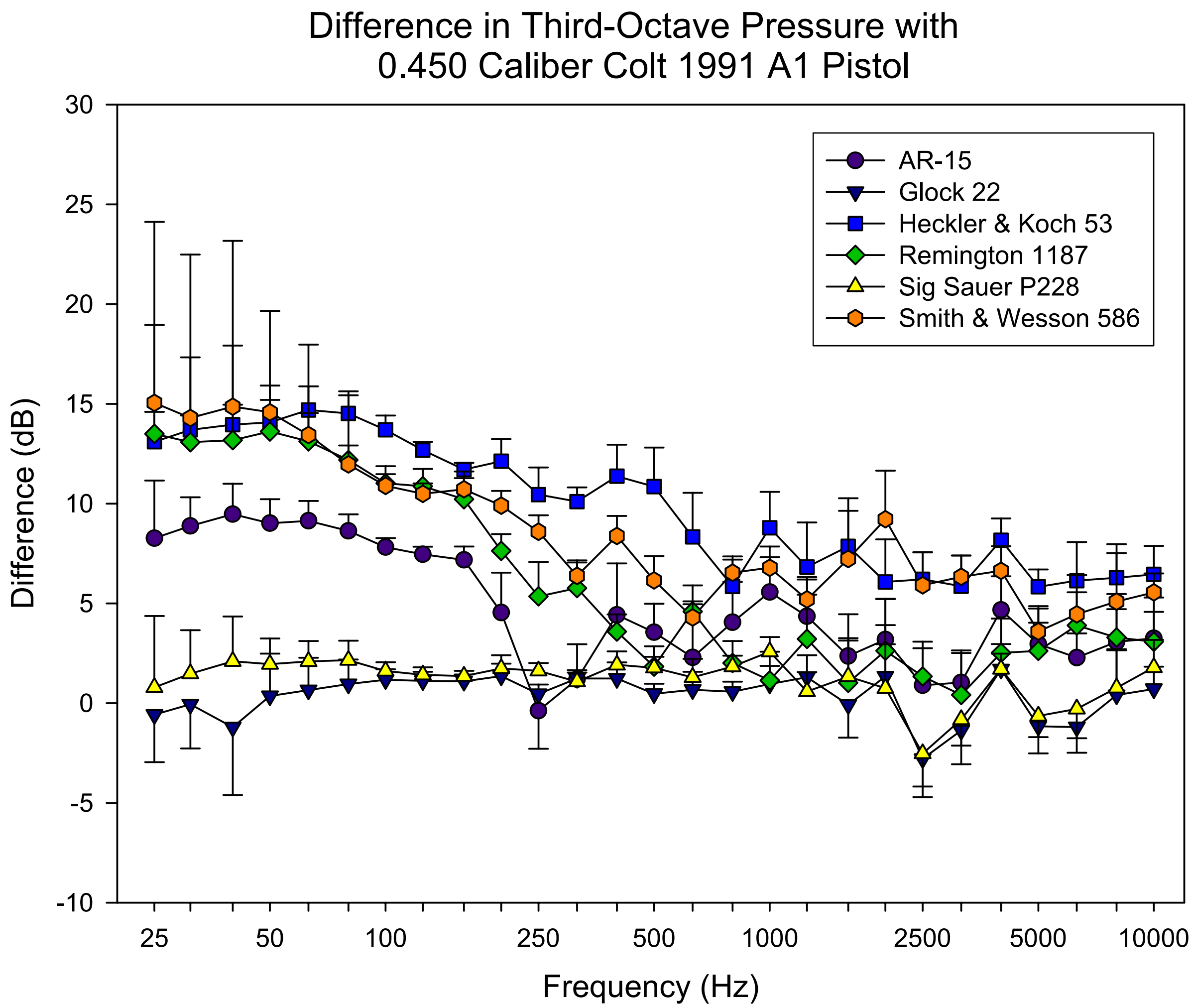


Figure 7
One third-octave band spectra for weapons measured at the outdoor firing range
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



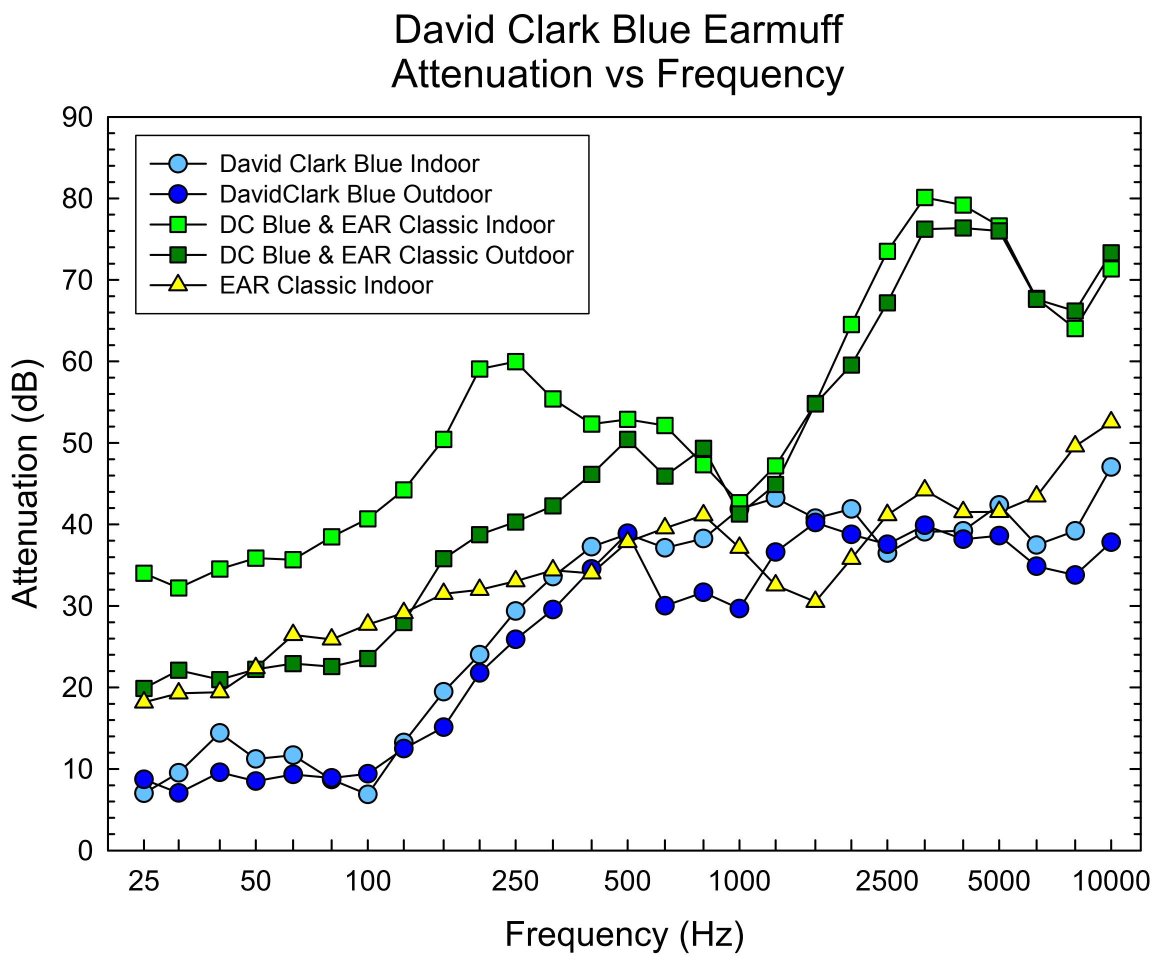
The horizontal lines are spaced in 10 dB intervals. The dark bar in the center depicts the 1000 Hz one third-octave band. The weapons are positioned with the lowest to highest sound pressure levels from front to back.

Figure 8
One third-octave band difference spectra for weapons measured at the outdoor firing range
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



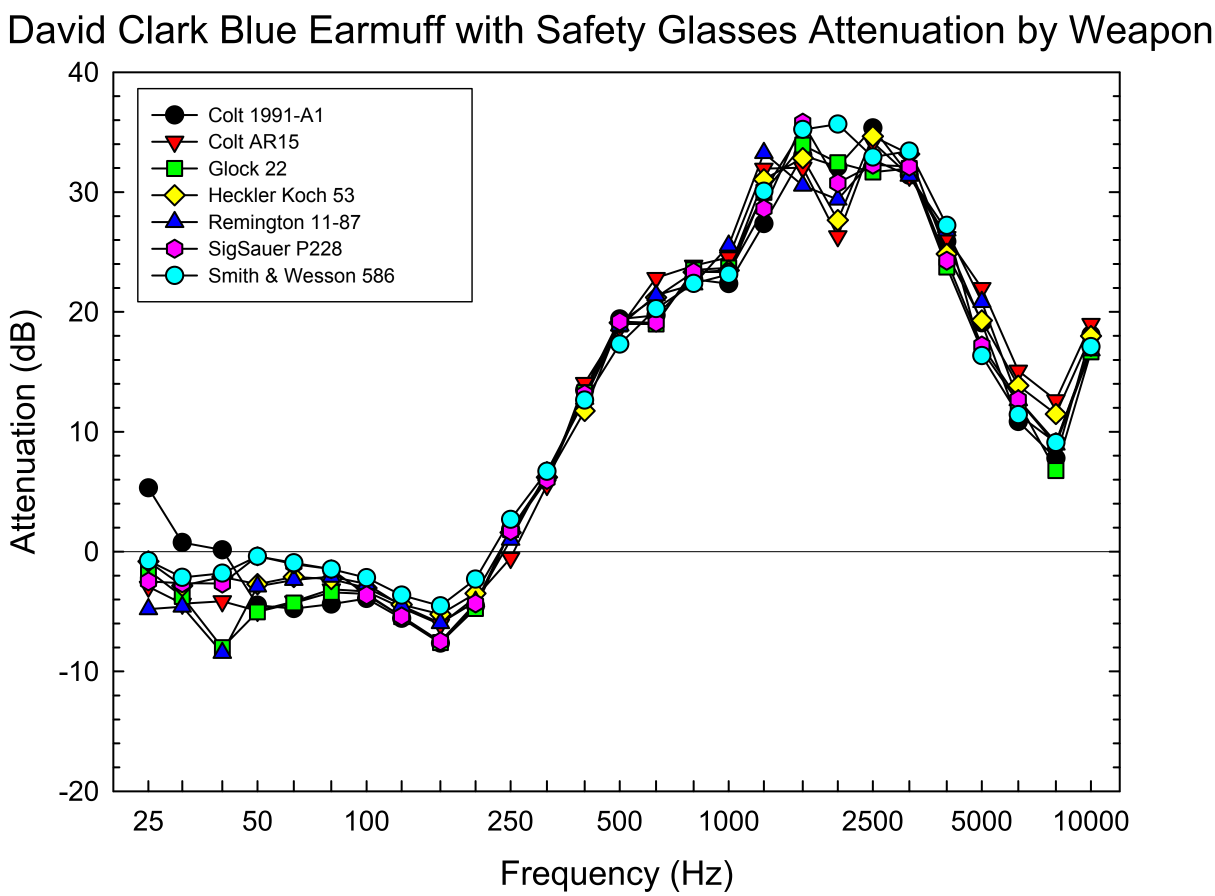
The .450 caliber Colt 1991-A1 semi-automatic pistol was used as the reference weapon. The Colt 1991 spectra was subtracted from the spectra of the other weapons to derive the difference spectra shown above. Error bars are depicted on one side of the data symbols to reduce clutter.

Figure 9
One third-octave band attenuation results for the David Clark Earmuff and EAR Earplug
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



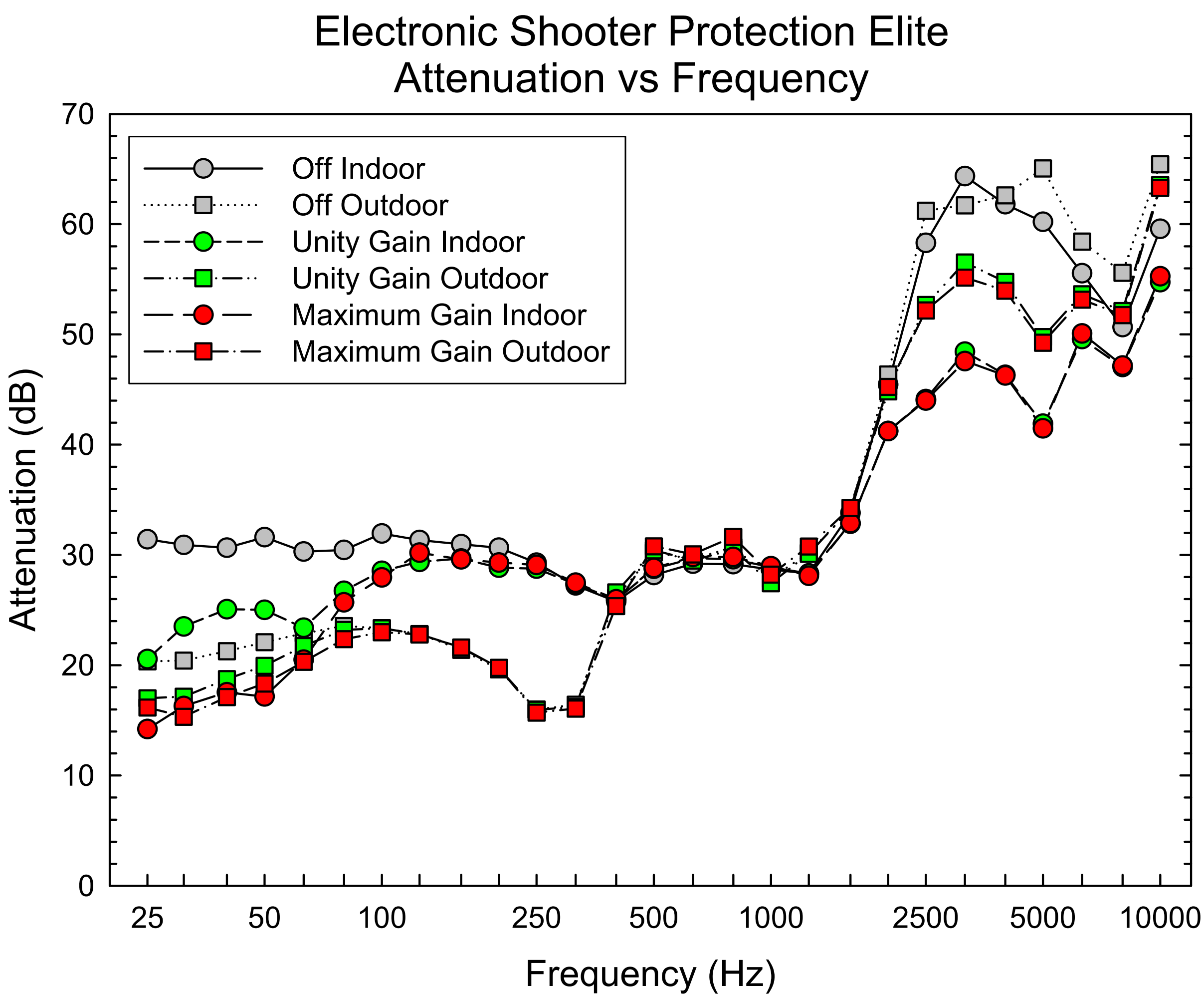
The third-octave band attenuation spectra for the David Clark model 27 earmuff alone and in conjunction with an EAR Classic earplug on the indoor and outdoor ranges.

Figure 10
One third-octave band attenuation results for the David Clark Earmuff and Safety Glasses
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



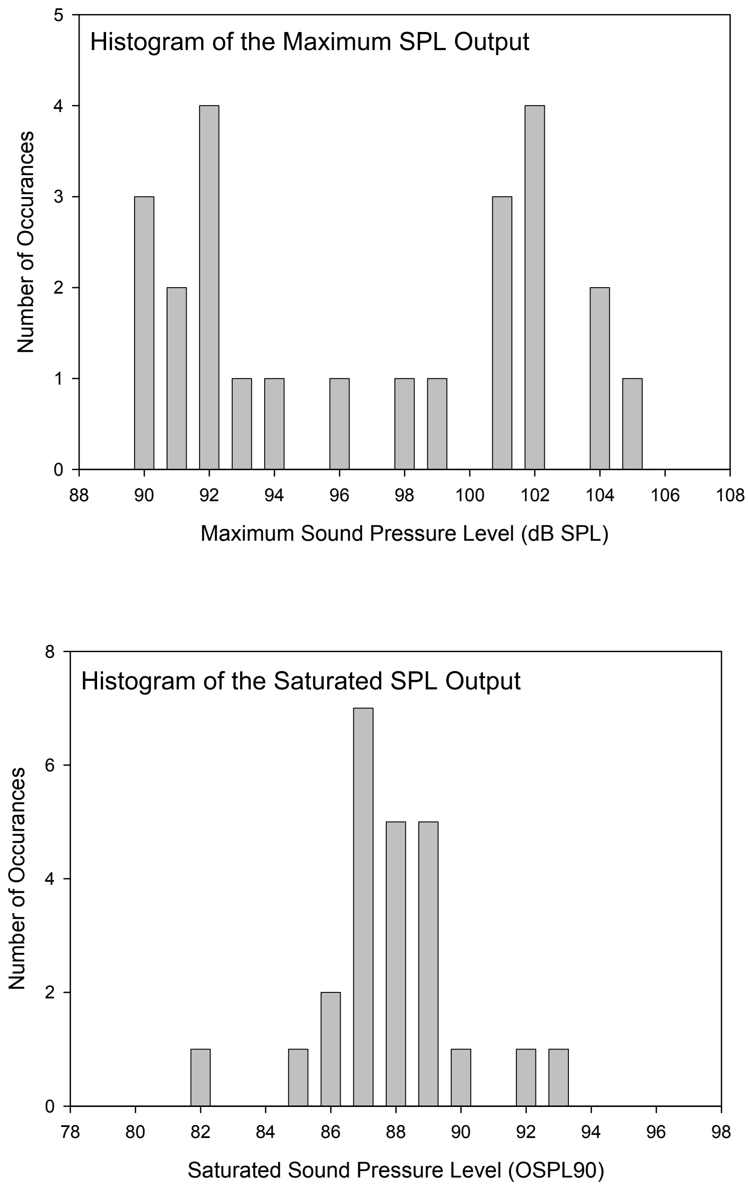
The third-octave band attenuation spectra for the David Clark model 27 earmuff with a leak caused by a pair of safety glasses under the earmuff. The different weapons are depicted with different colored symbols. The attenuations below 250 Hz are largely negative as a result of the leak. At 2000 Hz, the variation of the attenuations is larger than neighboring frequencies.

Figure 11
One third-octave band attenuation results for the ESP
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



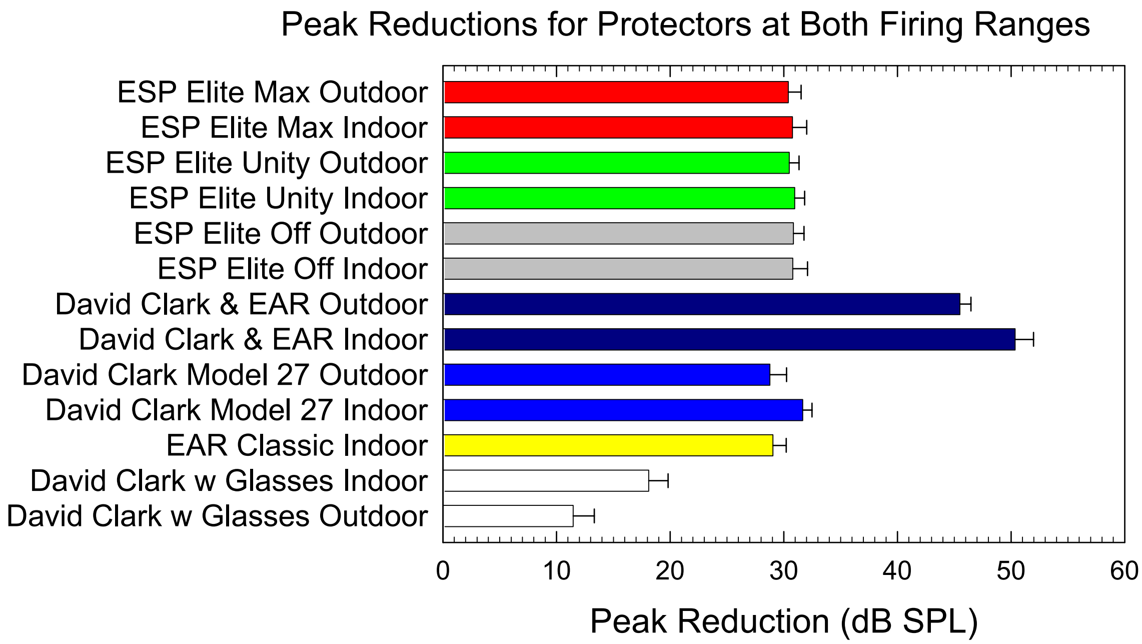
The third-octave band attenuations of the Electronic Shooter Protection Elite hearing protector for three different settings: off, unity gain, and maximum gain. The measurements for the indoor and outdoor firing ranges are different when the gain is applied whereas the off settings exhibit little difference above 100 Hz.

Figure 12
One third-octave band attenuation results for the ESP
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



Measurements for the ESP Elite device as tested according to ANSI S3.22-1996. The upper panel displays the histogram of the maximum sound pressure level (SPL) in dB along the x-axis for 24 units tested. One unit was for the ISL mannequin and one officer provided only one ESP Elite device. The lower panel shows a histogram of the saturated sound pressure level (SSPL) for the same 24 devices. The manufacturer's specifications indicate maximum SPL of 93 dB and SSPL of 88 dB.

Figure 13
Peak Reductions for the Hearing Protection Devices
Fort Collins Police Service
Fort Collins, CO
HETA 2002-0131
May 2002



The peak reductions for the protectors measured at both firing ranges. The maximum sound pressure level for the protected waveform was subtracted from the maximum sound pressure level for the unprotected waveform. The resulting difference is the peak reduction.

Table 1
Weapons Tested at the Indoor Firing Range
Fort Collins Police Services
Fort Collins, CO
HETA 2002-0131
May 2002

Manufacturer	Model	Caliber	Barrel Length	Weapon Classification
Smith and Wesson	686	.357	2.5 inches	revolver
Smith and Wesson	586	.357	6 inches	revolver
Colt	1991A	.450	5 inches	semi-automatic pistol
Para Ordinance	P10	.450	3.5 inches	semi-automatic pistol
Glock	27	.400	3.5 inches	semi-automatic pistol
Glock	22	.400	4.5 inches	semi-automatic pistol
Colt	Pocket9	9 mm	2.5 inches	semi-automatic pistol
Sig Sauer	P228	9 mm	4.5 inches	semi-automatic pistol
Remington	1187	12 gauge	18 inches	pump shotgun
Remington	870	12 gauge	18 inches	semi-automatic shotgun

Table 2
Weapons Tested at the Outdoor Firing Range
Fort Collins Police Services
Fort Collins, CO
HETA 2002-0131
May 2002

Manufacturer	Model	Caliber	Barrel Length	Weapon Classification
Smith and Wesson	586	.357	6 inches	revolver
Colt	1991A	.450	5 inches	semi-automatic pistol
Glock	27	.400	4.5 inches	semi-automatic pistol
Sig Sauer	P228	9 mm	4.5 inches	semi-automatic pistol
Heckler and Koch	53	.223	8.5 inches	automatic rifle
Colt	AR15	.223	20 inches	semi-automatic rifle
Remington	870	12 gauge	18 inches	semi-automatic shotgun

Table 3

Mean Temporary Threshold Shift (TTS) Values
Fort Collins Police Services
Fort Collins, CO
HETA 2002-0131
May 2002

Condition	Ear Tested	Time [sec.]	2000 Hz	3000 Hz	4000 Hz	6000 Hz
.223 cal Rifle - ESP protectors	Left	201.4	0.6 dB	-2.2 dB	-2.2 dB	-0.3 dB
	Right	263.1	0.0 dB	-1.2 dB	0.0 dB	-0.3 dB
.38, .40, .45 cal, 9 mm Revolvers	Left	124.6	-0.6 dB	-1.7 dB	-0.9 dB	-1.8 dB
	Right	196.7	-0.9 dB	-1.4 dB	-1.4 dB	-0.2 dB
.12 ga Shotguns	Left	132.1	-0.7 dB	0.7 dB	-0.4 dB	-0.7 dB
	Right	199.9	0.0 dB	0.0 dB	-0.7 dB	-3.2 dB
.223 cal Rifles	Left	203.2	0.2 dB	-1.9 dB	-2.1 dB	-1.5 dB
	Right	267.0	-0.2 dB	-1.2 dB	-0.4 dB	-1.2 dB

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226-1998

National Institute for Occupational Safety and Health
NIOSH

**Delivering on the Nation's promise:
Safety and Health at work for all people
through research and prevention**

To receive NIOSH documents or information about occupational Safety and Health topics contact NIOSH at:

1-800-35-NIOSH (356-4674) Fax:
1-513-533-8573 E-mail: pubstaft@cdc.gov
or visit the NIOSH web site at:
www.cdc.gov/niosh/homepage.html

SAFER • HEALTHIER • PEOPLE™