A Shot of Prevention: Firearms and Hearing Protection

Deanna K. Meinke, Ph.D.

Bringing education to life.

Rudyard Research Team

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*Specific products mentioned in this presentation are not for purposes of endorsement, but serve as examples of consumer products

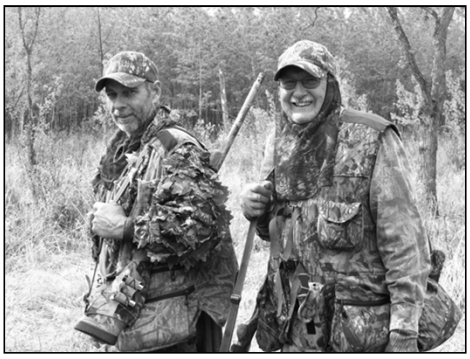
Learning Objectives

- Understand the unique signal characteristics of impulse/impact noise source and the hazard to hearing
- Identify factors that influence the auditory damage risk from recreational firearm impulse noise exposures
- Select the appropriate type of hearing protector for individuals exposed to recreational firearm impulse noise (hunters and target shooters).
- Understand the active and passive performance of electronic hearing protectors worn for impulse noise.

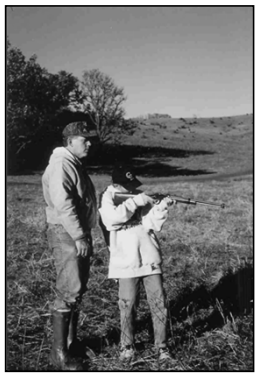
Overview

- Who is exposed to firearm noise?
- Firearms: The sound source
- Auditory Risk from Firearms
- Sound Exposure Variables
- Hearing Protection

Hunters



Youth Hunters




Target Shooters


Youth Target Shooters


Plinkers


Dog Trainers and Field Trial Participants

National Shoot to Retrieve Association (NSTRA)

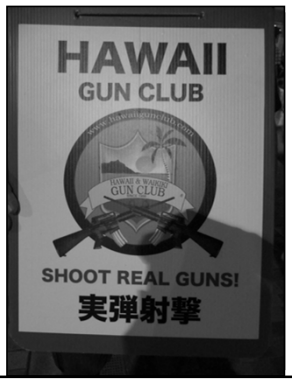
Group Shooting Events

Youth Group Shooters

Vacation Shooters

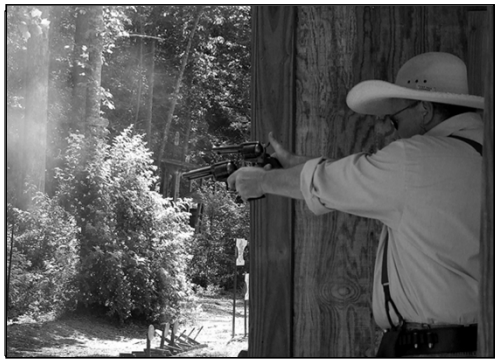
Maribuga Bay Resort in the Phillipines

Vacation Shooters

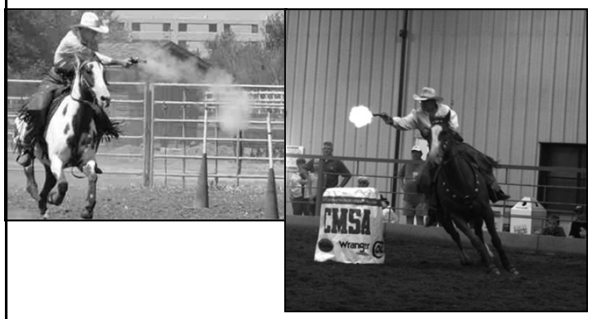


Vacation Shooters

Cowboy Shooters



Mounted Cowboy Shooters



Officials and Athletes Starter Pistol

ROTC

Police and Security

Fireworks: Impulse SPL

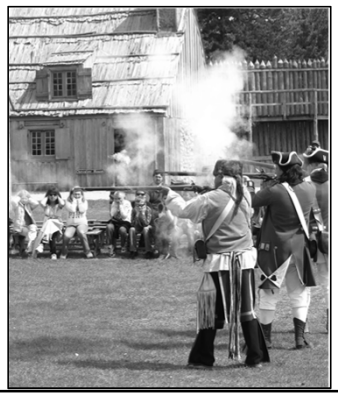
126-156 dB Peak SPL at 8 m.

Typically exceed 141 dB SPLpk

Demographics: Occupational

- ~ 4.5 million work/train with firearms not counting self-employed (DOL: Bureau of Labor Statistics: 2010, 2011)
  - **Police**: 794,300 (1 million projected by 2018)
  - **Military**: ~Active & Reserve 1,211,575 (fluctuates)
  - **Security & Gaming Surveillance Officers**: 1,090,600
  - **Game & Fish Wardens**: 7,240
-

Entertainers



Entertainers

Demographics

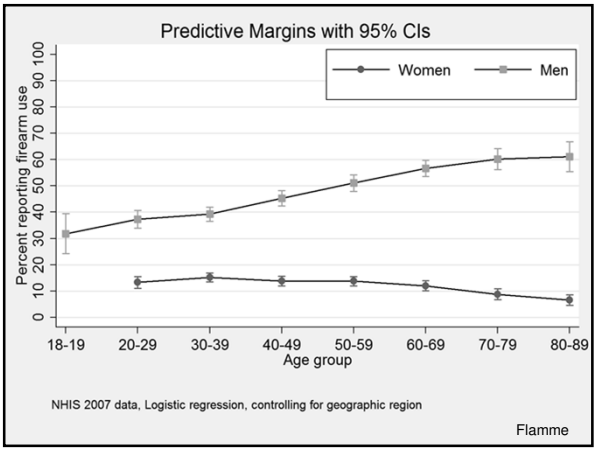
- National Rifle Association 2010:

(2010)	Households With a Gun	Adults Owning a Gun	Adults Owning a Handgun
%	40-45%	30-34%	17-19%
#	47-53 million	**70-80 million**	40-45 million

- U.S. Population = 315.5 million (March, 2013)

Demographics

- NRA: 70 million own guns
  - NRA (2005): 45% of men & 13% of women own a gun
  - NHIS (2007): 46% of men & 13% of women have fired a gun, most of these shooting over 100 rounds.

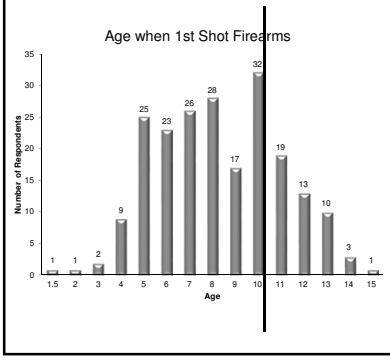


Demographics

- Hunters: (U.S. FWS, 2001 & 2006; Southwick & Associates, 2010)
  - 28 million Americans consider themselves hunters
  - 18 million over the age of 16 hunted an average of 18 days a year during a five-year period 2002-2006.
  - 1.74 million were youth aged 6-15 years

Shooting Habits of Youth

n=210 aged 10-18 years



Stewart et al., 2014

Demographics

- Sports Shooters (hunters, cowboy shooters etc.)
  - 20.6 million Americans (NSSF, 2009)
  - 19 million active target shooters (skeet, trap and sporting clays)

Target Shooter and Bystander

Other Bystanders

Overview

- Who is exposed to firearm noise?
- Firearms: The sound source
- Auditory Risk from Firearms
- Sound Exposure Variables
- Hearing Protection

Firearm Sound

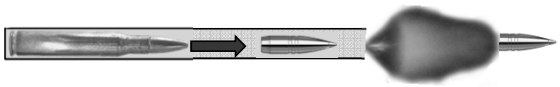
- The sound created by recreational firearms used in hunting or target practice is characterized by a high-frequency, short-duration impulsive noise. This signal is perceived by the human ear as one single, loud impulse or “shot.”

Impulse noise

- Impulse Noise: usually considered to be singular noise pulses, each less than 1 second in duration, or repetitive noise pulses occurring at greater then 1 second intervals.
- Also defined as a change of sound pressure of 40 dB or more within 0.5 sec.

Basics of Gunshot Noise

1. Gunpowder burns, producing expanding gasses
2. Projectile is pushed forward by the force of the gasses
3. Projectile and gasses exit the muzzle of the gun.
   - Gasses cause a pressure (shock) wave that expands in three dimensions. Sound!



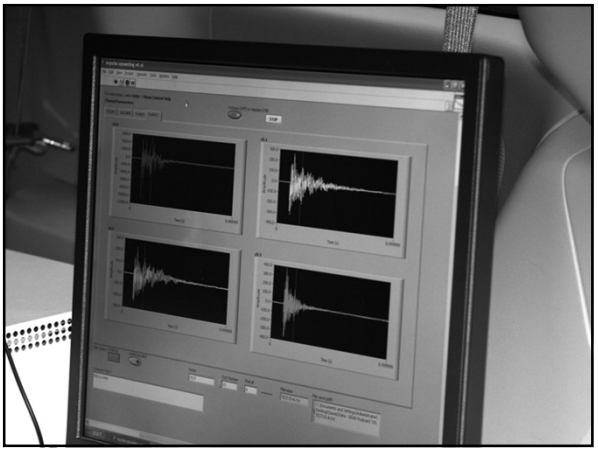
Finan

Shock (pressure) wave

http://www.americanscientist.org/issues/pub/high-speed-imaging-of-shock-waves-explosions-and-gunshots/1

Measuring Recreational Firearms

Rasmussen et al.
http://www.sandv.com/aug09.shtml



Shock (pressure) wave

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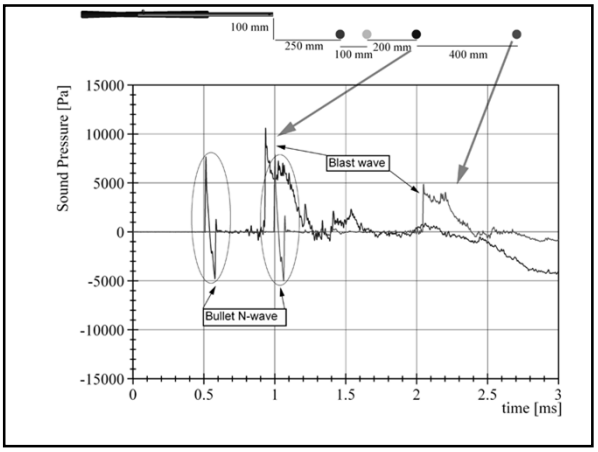


Impulse (and impact) Hazard

- 140 dB peak sound pressure level limit
  - OSHA 29 CFR 1910.95 (1983)
  - MSHA 30 CFR, Part 62 (1999)
  - FRA 49 CFR 227 and 229 (2007)
  - NIOSH Pub. No. 98-126 Criteria Document (1998)
  - U.S. MIL-STD-1474D (U.S. DoD, 1997)
  - EPA (1974)
  - WHO (1999)
    - *120 dB peak SPL for children

Impulse Hazard

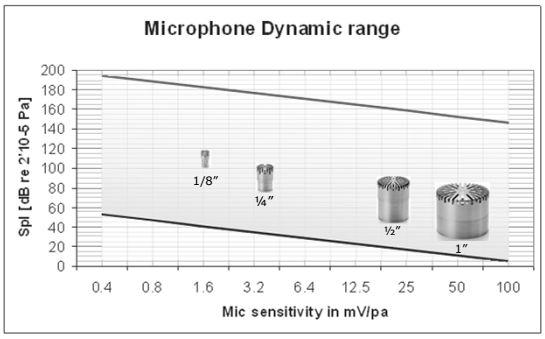
- Damage Risk Criteria (DRC)
  - Total energy contained in the impulse (L_{Aeq8})
  - Frequency spectrum
  - Pressure wave (A duration)
  - Pressure envelope (B duration)
- Briefly, the A-duration is the time interval between the initial pressure rise of the impulse and the moment the pressure passes through ambient.
- The B-duration is the time interval during which the envelope of the signal resides within 20 dB of the peak pressure.

Measuring with a Sound Level Meter

- Microphone limitations
- Inadequate power supply
- Frequency weighting (response)
  - A-weighting
  - C-weighting
- Averaging
  - "Fast" (125 ms)
  - "Impulse" (5ms rise, 1.5 s falling)

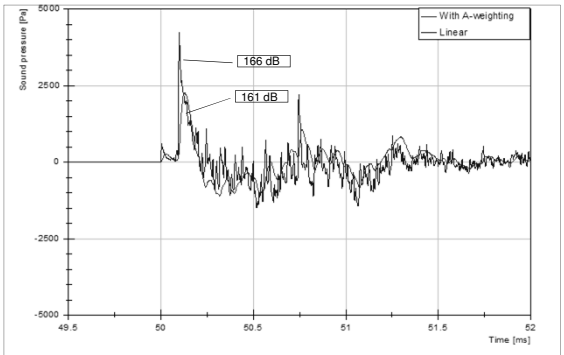
Slide courtesy of Per Rasmussen, GRAS Sound and Vibration

Microphone sensitivity



Slide courtesy of Per Rasmussen, GRAS Sound and Vibration

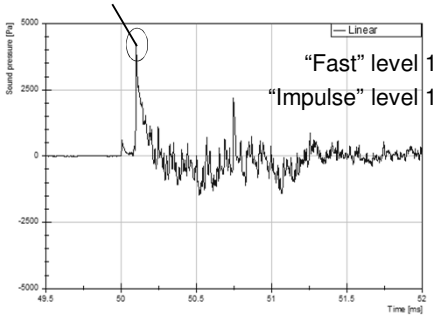
Effect of A-weighting



Slide courtesy of Per Rasmussen, GRAS Sound and Vibration

Averaging times

Peak level 166 dB



"Fast" level 137 dB

"Impulse" level 140 dB

Slide courtesy of Per Rasmussen, GRAS Sound and Vibration

Overview

- Who is exposed to firearm noise?
- Firearms: The sound source
- Auditory Risk from Firearms
- Sound Exposure Variables
- Hearing Protection

Acoustic Trauma

- Single exposure to intense sound leading to permanent hearing loss
  - At or above ~125-130 dB peak SPL

Acoustic Trauma

- "At high levels of acoustic energy, delicate structures are ripped apart." (Hamernik & Henderson, 1974)
  - Organ of Corti ripped from basilar membrane
  - Pillar & Hensen's cells destroyed
  - Cell junctions between HCs and Deiter's cells & Hensen's cells broken. (Hamernik,Turrentine, & Roberto, 1986)
  - Small lesion initially but grows over 2-30 days after exposure (Hamernik et al., 1986)

Hearing Loss from Firearms

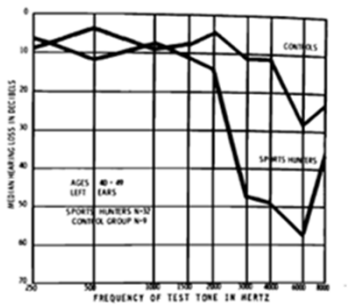


FIG. 11. Median hearing loss in habitual sports shooters and age-matched controls. [From Taylor and Williams (1966) with the permission of the authors and *Laryngoscope*.]

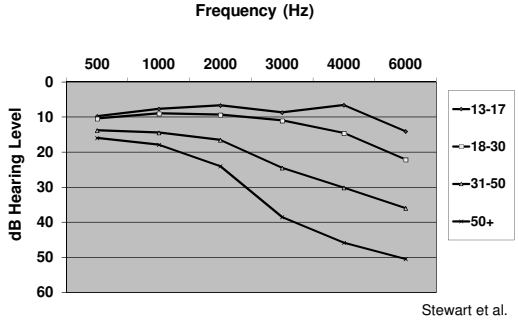
Research in Recreational Firearm Noise Exposure at CMU (1997-2012)

- Shooting Habits
  - Adults (2)
  - Youth
  - Deer hunters
  - Waterfowl hunters
  - Females

- Hearing loss & hearing handicap in shooters
- Tinnitus in shooters
- Shooters knowledge of hearing conservation

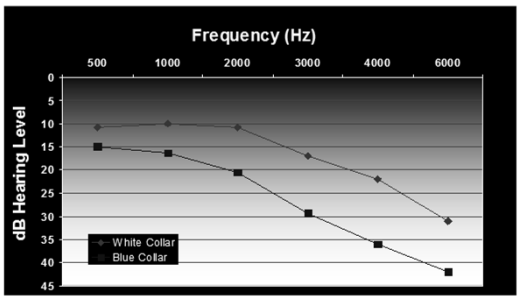
Stewart et al.

Mean Binaural Audiograms of Shooters: As a function of age in years (N=233)



Stewart et al.

Mean Binaural Audiograms
(Blue Collar vs White Collar Hunters n=232)



Stewart, M., Pankiw, R., Lehman, M.E., and Simpson, T.H. (2002). Hearing loss and hearing handicap in users of recreational firearms. J. Am Acad Audiol, 13, 160-168.

Constant Tinnitus

Study	YES RESPONSES	Mildly Annoying	Moderately Annoying	Severely Annoying
HHI	NA			
Risk Patterns & Shooting Habits*	**19%**	70%	23%	7%
Shooting Habits of Waterfowl Hunters	**21%**	75%	21%	4%
Knowledge of Recreational Shooters	**22%**	67%	22%	9% (2% no response)

Stewart et al.

Self-Reported Tinnitus

- WATERFOWL HUNTERS:
  - 51% of respondents reported experiencing tinnitus after hunting
    - Several hunters reported that it occurred every time after hunting.
    - On average, 25% of respondents reported it occurred 5-10 times throughout the season.
- WILDLIFE CONSERVATION MEMBERS
  - 65% note tinnitus or increase in tinnitus after shooting.

Stewart et al.

Current Use of Amplification

- Currently utilize amplification:
  - Yes = 3.7% (n = 11)
    - Bilateral users = 7
    - Unilateral users = 4
  - No = 96.3% (n = 286)

Stewart et al.

Overview

- Who is exposed to firearm noise?
- Firearms: The sound source
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- Sound Exposure Variables
- Hearing Protection

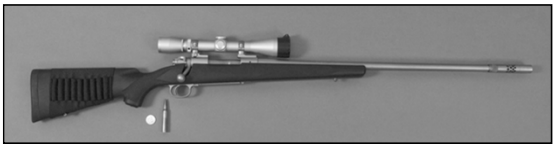
Sound Exposure Variables

- Type of Firearm / Amount of powder
- Distance to the ear
- Firearm modifications
- Number of shots
- Shooting environment
- Hearing protection

Types of Contemporary Recreational Firearms

- RIFLES:
  - Rabbits
  - Deer
  - Elk
  - Bear
  - Sheep
  - African Game

Rifles: Winchester 7mm Mag

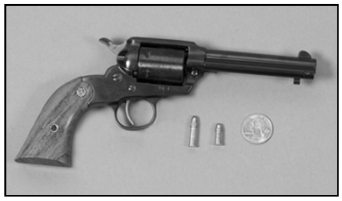


166.5 dB Peak SPL

Types of Contemporary Recreational Firearms

- PISTOLS:
  - Rabbits
  - Deer
  - Bear
  - Elk

Pistol: Ruger .22 LR



154.0 dB Peak SPL

Types of Contemporary Recreational Firearms

- SHOTGUNS:
  - Quail
  - Pheasants
  - Ducks
  - Geese
  - Deer
  - Turkey

Shotgun Gauges

Shotguns: Remington 12 gauge

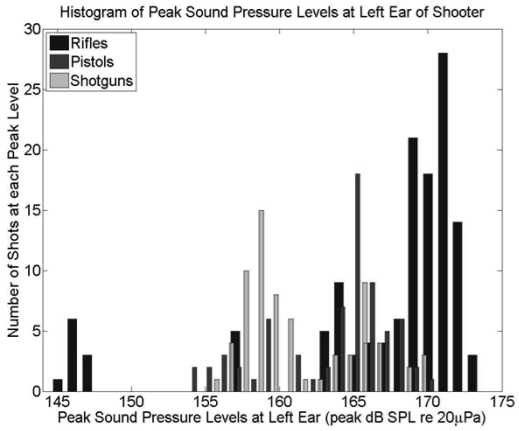
160.1 dB Peak SPL

Modern Cartridges / Shells

- Pistol
- Rifle
- Shotgun

Modern Cartridges

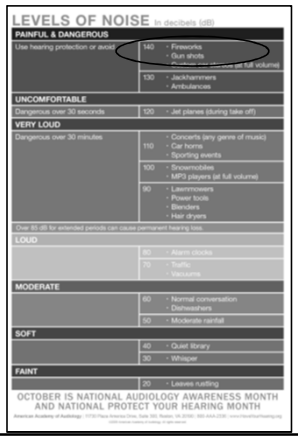
- .50 BMG
- .300 Win Mag
- .308 Win
- 7.62 x 39mm
- 5.56mm NATO
- .22



Firearm peak levels

- Rifles
  - ~163 to 174 dB SPL_{pk}
  - Smaller .22's ~144 dB SPL_{pk}
- Pistols
  - ~ 148 to 171 dB SPL_{pk}
- Shotguns
  - ~156 to 170 dB SPL_{pk}

See handout for Peak dB SPLs
for specific firearms
(5 published studies)



Sound Exposure Variables

- Type of Firearm / Amount of powder
- Distance to the ear
- Firearm modifications
- Number of shots
- Shooting environment
- Hearing protection

Barrel Lengths

Sound Exposure Variables

- Distance to ear

Sound Exposure Variables

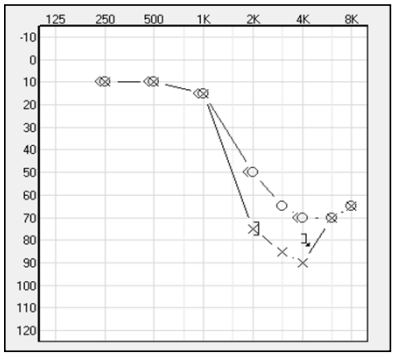
- Distance to ear

Sound Exposure Variables

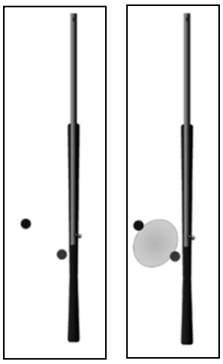
- Distance to ear

Youth Target Shooting: Changes Distances

Firearm noise-induced hearing loss

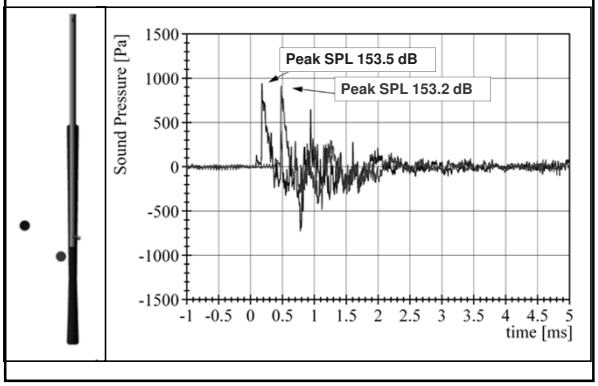


Head Position

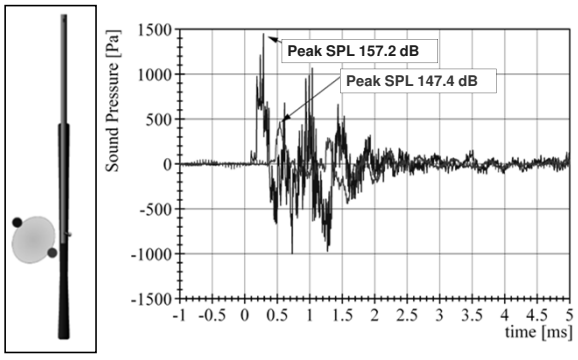


- Simultaneous measurements on Left and Right side
- Winchester model 43
  - .22 caliber Hornet
- Sound field changed by the presence of the head
  - Diffraction
  - Shadowing

Head Position: Absent



Head Position: Rt. Handed shooter



Starter Pistols

Video

Sound Exposure Variables

- Distance to ear: Starter Pistol / Revolver

Starter Pistols vs. Revolver

Table 1. Mean peak SPL value for .22 and .32 caliber firearms.

	Impulse peak SPL (dB) at different measurement positions			
Pistol	*5 cm from shooter's ear*	*Chamber: 10 cm to side*	*Muzzle: 10 cm to side*	*Muzzle + 1.5 m*
Kimar .22 starter pistol	[redacted]	179.8	177.1	157.1
K-22 revolver w/blanks	147.9	157.3	173.7	158.9
K-22 revolver w/CCI LR	158.1	180.7	174.9	154.0
K-22 revolver w/shorts	155.1	177.1	172.0	154.7
.32 starter pistol	[redacted]	179.3	182.0	157.4
.32 revolver w/blanks	151.2	166.3	174.3	161.7
.32 revolver w/W325	152.7	168.5	176.5	157.2

7-18 dB higher levels for blocked barrel starter pistols as compared to comparable caliber pistol shooting live rounds or blanks.

Meinke et al, 2013, Int'l J Aud; 52: S9-S19

Officials and Athletes Starter Pistol

167 dB Peak SPL at 0.5 m

148 dB_{pk} at 4m (nearest athlete)

134 dB_{pk} at 14m (distant athlete)

Meinke et al., 2014

Recreational Firearm Exposure: Bystanders

Bystander Exposure

J Am Acad Audiol 22:93–103 (2011)

Auditory Risk to Unprotected Bystanders Exposed to Firearm Noise

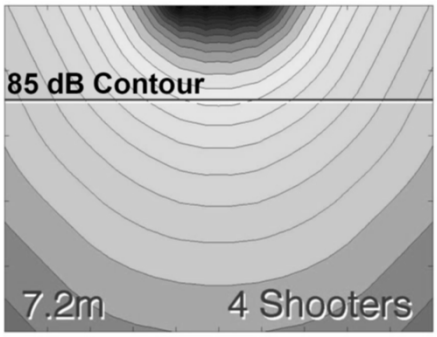
DOI: 10.3766/jaaa.22.2.4

Gregory A. Flamme*
Michael Stewart†
Deanna Meinke‡
James Lankford§
Per Rasmussen**

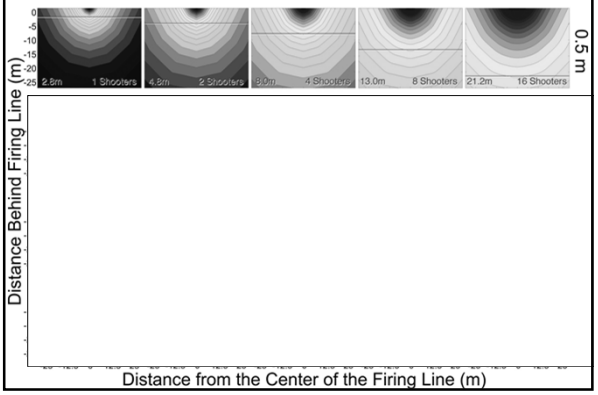
- Impulses from 15 recreational firearms were obtained 1m to the left of the shooter
- Instantaneous peak levels at the bystander location ranged between 149 and 167 dB SPL

Multiple Shooters: Propagation Modeling

Bystander Foul Line



Visualization of 85 dBA Foul Lines



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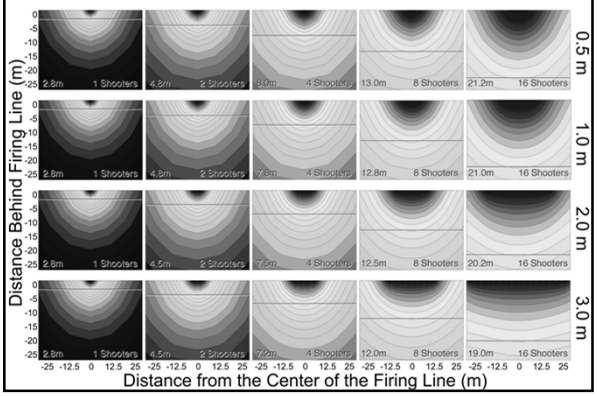
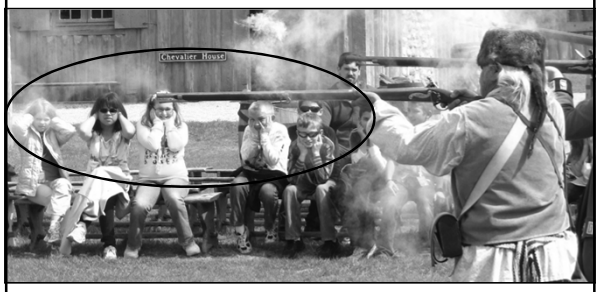


Recreational Firearm Exposure: Bystanders

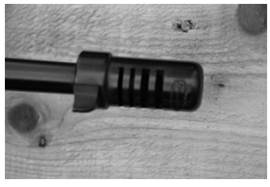


Sound Exposure Variables

- Type of Firearm / Amount of powder
- Distance to the ear
- Firearm modifications
- Number of shots
- Shooting environment
- Hearing protection

Sound Exposure Variables

- Muzzle brakes / ports
- Suppressor (silencer)



Sound Exposure Variables

- Type of Firearm / Amount of powder
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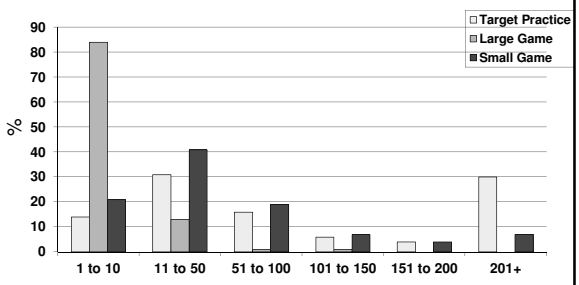
Variables & Ballistics

- Number of shots

Reported Number of Shots Fired

(for current year hunting season)



Stewart et al.

Sound Exposure Variables

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Shooting Environment

There are many instances in which impulse noise may be produced near surfaces that may reflect the acoustic energy, or within enclosed chambers, where reverberation is likely to occur…

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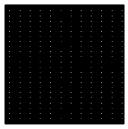
Sound Reflection & Reverberation

- Reflection: sound waves that encounter a flat surface will reflect coherently. Hard, nonporous surfaces produce the greatest, most coherent reflection.

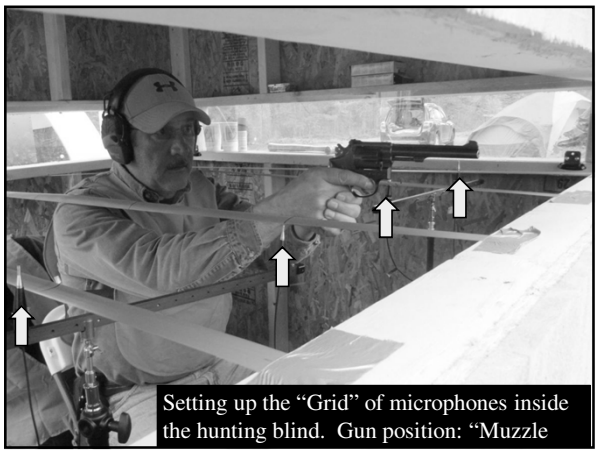
- Reverberation: prolonged acoustic energy in an enclosed space due to reflection.

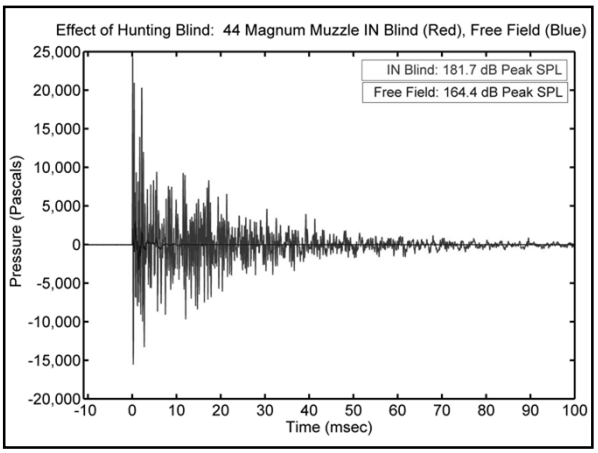


Finan

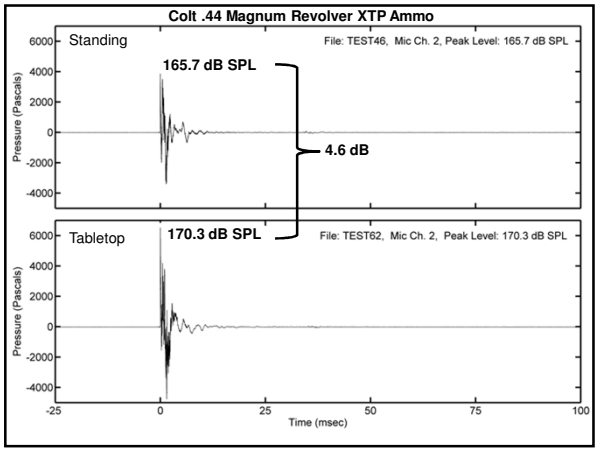
Cowboy Action Shooting sets

Deer Hunting Blind


Setting up the "Grid" of microphones inside the hunting blind. Gun position: "Muzzle



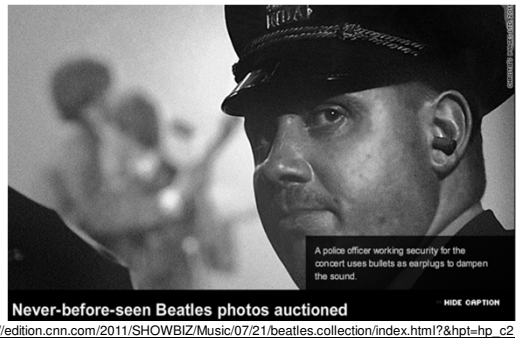
Standing vs. Tabletop



Sound Exposure Variables

- Type of Firearm / Amount of powder
- Distance to the ear
- Firearm modifications
- Number of shots
- Shooting environment
- Hearing protection

Hearing Protection ?

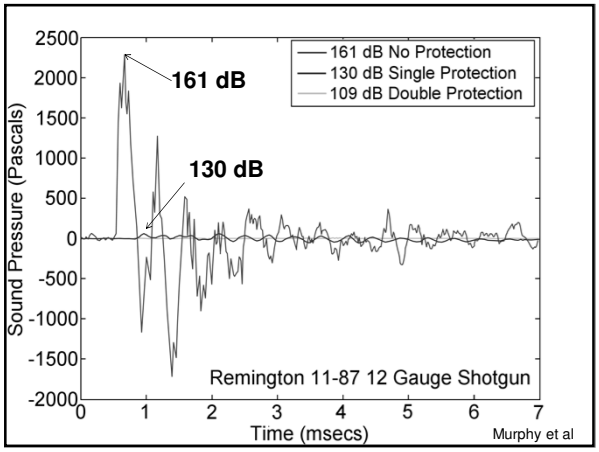


http://edition.cnn.com/2011/SHOWBIZ/Music/07/21/beatles.collection/index.html?&hpt=hp_c2

HPD Use: Target Shooting vs. Hunting

- 16 to 30% NEVER wear HPD while target shooting
- 39 to 52% ALWAYS wear HPD while target shooting
- 76 to 83% NEVER wear HPD while hunting
- 6 to 8% ALWAYS wear HPD while hunting

Stewart et al



Murphy et al

Device Terminology

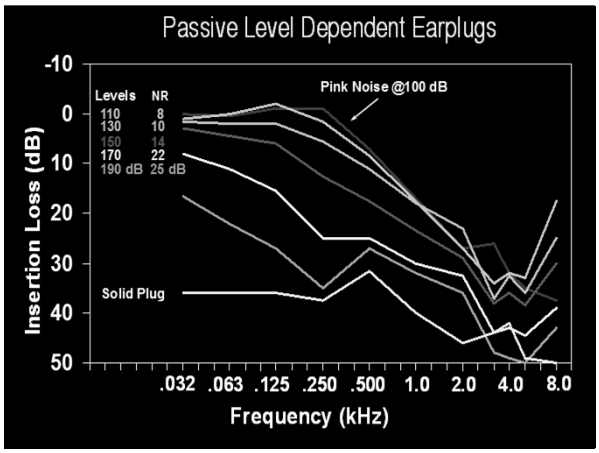
- Conventional passive
- Linear or Non-linear (amplitude-sensitive)
- Active, Level Limiting or Sound Restoration
  - Designed for impulse noise vs.
  - Active Noise Reduction (ANR)

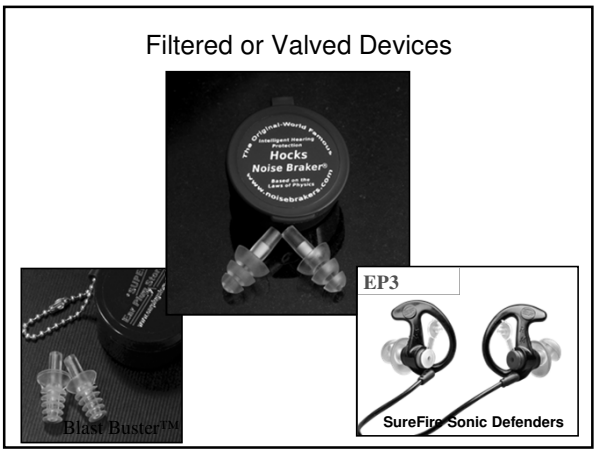
Specialty Devices

- Special devices have been developed to afford adequate attenuation AND preserve or augment auditory perception.
- Safety Considerations: If you really think about it; anyone with a firearm in their hands or near a firearm user, should be able to communicate effectively.
- Especially when learning to shoot

Passive: Filtered or Valved Devices

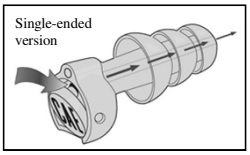
- Structural elements and mechanical devices such as small apertures, ducts, diaphragms, dampers, valves , and springs.
- Nonlinear acoustical behavior develops when high-level sound (above 120 dB) impinges on the small opening.
  - Laminar airflow for lower intensity sounds pass through
  - Turbulent airflow for higher intensity sounds increase acoustic resistance within the aperture.



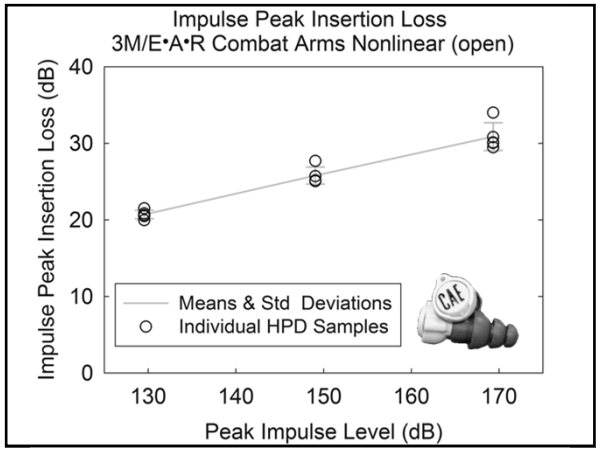


Combat Arms™ Level-Dependent Earplugs

- Switch between two different modes
  - Hear-though mode allows normal listening
  - Continuous protection mode provides constant noise reduction
  - NRR = 22

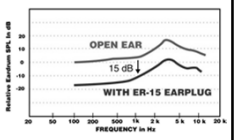


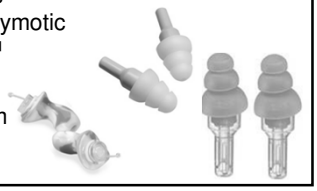
Slide courtesy of 3M: Madison & Berger



Uniform "Flat" Attenuation

- Attempts to restore the natural sound spectrum for the listener with linear attenuation from ~100-8000 Hz.
- Marketed as "Musicians Earplug" Ety-Plug by Etymotic Research or 3M Hi-Fi™
- Also available in custom products





Electronic Hearing Protectors

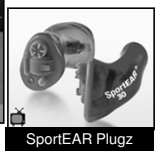
- Amplitude sensitive = Level dependent function
- Modified conventional earmuff or earplugs with external microphone
- Output limited amplifier
  - Usually maintains output at 82-85 dBA earphone level
  - Cutoff level of 115-120 dBA, electronics cease function.
- Specific band-pass frequency characteristics possible (e.g. speech Hz).
- Specific amplification paradigm possible

Electronic protectors

- Impulse durations too brief for compression
- Hearing aids and electronic circuits have about 5 ms attack times
- Impulse durations are less than 5 ms
- IT IS THE PASSIVE FIT OF THE DEVICE THAT PROVIDES THE ATTENUATION

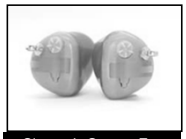
Electronic Hearing Protector Examples


3M Peltor Tactical Sport


SportEAR Plugz


Howard Leight Impact Sport


Walker's Bone Collector


Siemen's Secure Ear

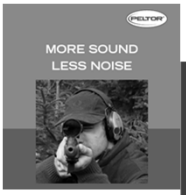
3M™: Peltor™ Tactical Sport™

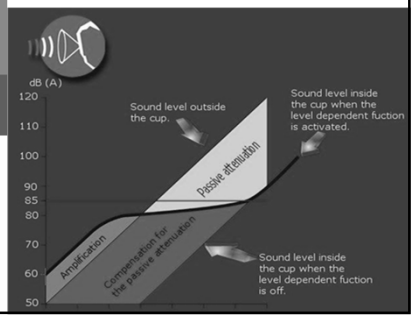
NRR = 20

- Low level amplification
- J22 audio input for hunting radio or dog tracker connection
- Gun stock recess
- ON/OFF and VC adjustments
- Directional microphones on each cup

Price: ~$92.00

Peltor: Sport-Tac (Tactical) Earmuffs





Modular Custom Fit


DefendEar Digital 1

- Amplification for situational awareness.
- Noise attenuation when you pull the trigger.


DefendEar Digital 2

- **Game mode:** Optimized for intermittent shots.
- **Clay mode:** Optimized for continued shots.


DefendEar Hunter

- **Normal mode:** provides standard Digital 1 features.
- **Wind Reduction mode:** Ideal for shooting in windy conditions.

Howard Leight by Honeywell: Impact® Sport Electronic Earmuffs

NRR = 22

- Low profile cup
- Single ON/OFF & VC knob
- External audio plug
- Water resistant
- Amplification to 82 dB
- 350 hour battery life
- auto shut-off 4 hours

Price: ~$58.00

Creative Approach?

Howard Leight by Honeywell: Impact® Pro Electronic Earmuffs

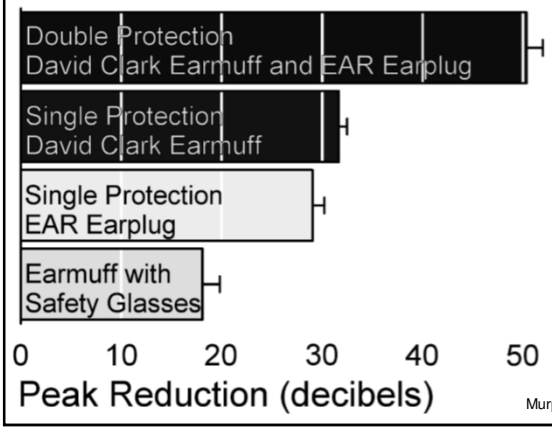
NRR = 30

- "Extreme hearing protection" for handgun shooters, especially at indoor ranges.
- "voice amplification for communication on the range"
- Audio jack for connection to music, radios, scanner, phones
- Single ON/OFF and VC knob

Price:$78.99

Mutt Muffs

Price: ~$38-$59



Marketing Ploys: Beware

- Valved earplug retail site: "….only type of hearing protector that attenuate high-level noises while allowing low-level environmental sound to pass through".
- Filtered earplug manufacturer site: "As a result, no sound over approximately 85 decibels is allowed to pass through the filter into your ear! "
- Common: "can hear distant whispers"
- Common: "… potentially harmful sound levels above 85dB are reduced to safe levels."

How high above?

Passive: Filtered or Valved Devices

- Advantages:
  - Less expensive
  - Durable
  - Low maintenance
  - Does not rely on power source (no batteries)
  - Small and easily carried and stored
- Disadvantages
  - Limited in acoustic and communication features
  - Filtered components may become damaged or blocked
  - Valved components may unknowingly fail
  - Small may be easily displaced or lost

Electronic: Ear Muffs

- Advantages:
  - Advanced acoustic and communication features
  - Provides amplification if needed for hearing-impaired or to augment natural hearing
  - Provides insulation from the cold
  - Passive attenuation possibly more consistent

Expense?

- Disadvantages
  - Batteries may go bad (depleted or temperatures)
  - Wind noise across microphones
  - Durability in field/weather conditions ?
  - Interferes with shouldering a weapon
  - More susceptible to slit leaks from glasses / hats

Electronic: Ear Plugs

- Advantages:
  - Advanced acoustic and communication features
  - Provides amplification if needed for hearing-impaired or to augment natural hearing
  - Custom-shaped to ear, possible comfort advantage?
  - Small and easily carried and stored
  - Less susceptible to slit leaks from glasses / hats
  - Does not interfere with shouldering a weapon
- Disadvantages
  - More expensive
  - More easily displaced or lost
  - Power source (batteries) may be depleted or limited by temperatures)
  - Wind noise across microphones
  - Durability in field/weather conditions ?
  - Passive attenuation dependent upon shell fit

The Problems with the NRR…

- Designed for Continuous Noise
- Typical protectors exhibit nonlinear response at high levels >140 dB SPL
- Nonlinear orifice protectors provide increased attenuation with increasing peak Sound Pressure Level (peak SPL).
- Electronic Protectors are designed to limit output to levels below about 82 dB peak SPL.

Murphy, W.

Proposal: Impulse Noise Reduction

- Measure the Performance for protectors for levels from 130 to 170 peak SPL.
- Measure performance over a range of levels (130-134), (148-152) and (166-170) dB.
- Measure the device on an Acoustic Test Fixture (ATF) to limit human subject exposure.
- Measure both Free-field and ATF waveforms and apply signal processing to the determine the impulse noise reduction rating.

Murphy, W.

Terminology

- Impulse Peak Insertion Loss (IPIL)

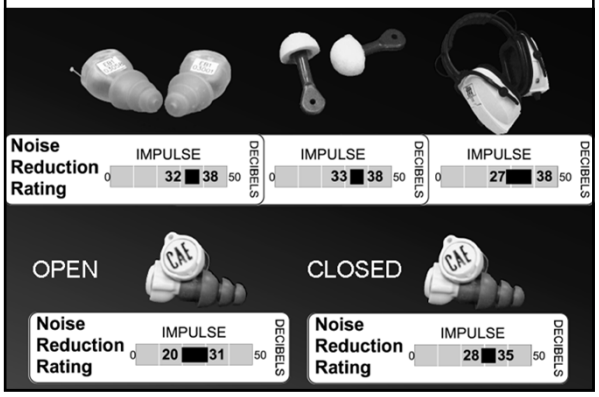
  $Eardrum_{protected} - Eardrum_{unprotected}$

- Peak reduction

  $Eardrum_{protected} - Field$

14
4

How Impulse Labels Might Look



Fit is Critical

Audibility / Intelligibility Demands of Hunters

- Interpersonal communication for safety & logistics
- Audibility of animal sounds
- Audibility of firearm function
- Audibility of dog beeper collars, GPS
- Monitoring of their calling sounds
- Localization is critical

Communication is Critical for Safety

Adult Mentoring Needed

Dangerous Decibels™

www.dangerousdecibels.org

Summary Advice for Shooters

- Always wear HPDs when shooting
  - Keep earplugs handy, put in all ammo boxes, gun cases
- Double protect with high power firearms & if wearing glasses
- Use non-linear or appropriate electronic ear protection for hunting or when audibility is critical
- Recognize that temporary hearing loss and/or tinnitus after shooting is a warning sign of ineffective protection

Summary Advice for Shooters

- Consider shooting smaller calibers when possible
- Choose a single shot or bolt over a semi-auto
- Avoid high risk situations (e.g. shooting inside reverberant areas, over hard surfaces)
- Annual hearing tests to confirm protector effectiveness
- Use hearing protection for other hazardous sound exposures

Individual Exposure Considerations

- How often firearms used
- Number of shots fired
- Type of firearm
- Size of the gun
- Size of the caliber or gauge
- Firearm modifications
- Type of ammunition
- Hunter vs. Target/Skeet Shooting
- Indoor vs. Outdoor
- Acoustic characteristics of the impulse
- Protected vs. Unprotected
- Hearing protector fit and effectiveness

www.hearingconservation.org

THANK YOU!

Deanna.Meinke@unco.edu