Hearing Protection Devices

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History in U.S.

- Great interest in WWII due to hearing loss in the military
- 1950s: hearing protection programs started
- OSHA: started in 1972
  - 1983: Revised hearing conservation standard
- Quality of protectors improved over the years
- Greatest issue still is appropriate use by users

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Selecting the Right Hearing Protector

- More art than science: must be able to motivate management to enforce and workers to wear
- Computations are estimates
- Most often, exposures $\leq$ 95 dBA, so need $\leq$10 dBA attenuation
  - Easy to achieve IF WORN
  - Comfort, communication, cost, etc. become most important
  - Can often afford to use less than best if gives better compliance

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Noise Reduction Rating

- Efficacy tests originally done using frequency data
  - Difficult to do before personal computers
- EPA, 1970
- OSHA adopted in 1983
- Seemed to provide accuracy and simplicity
- Laboratory ratings are unrealistic, giving inflated ratings
- Since NRR relies on them, it provides little helpful guidance
- Instead, IHs should wear each of them 8 hours to see how comfortable, etc.

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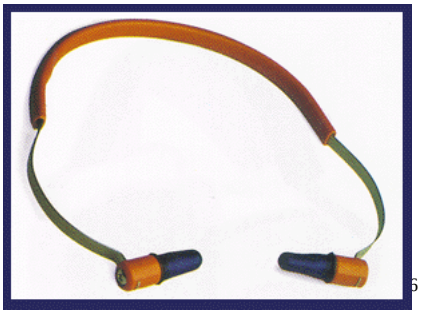
Ear Protection

- Earplugs: for modest exposures
- Ear muffs: for high exposures
- Both: for extremely high exposures (>100dBA)
- Must be comfortable



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Types of HPDs, Features, and Usage Characteristics

- Earplugs:
  - Placed into or against the opening to the ear canal
  - Form a seal and block sound
  - Most comfortable and convenient
  - About 85% of employees prefer them over ear muffs, but some cannot stand having anything in their ears and may take time to adjust
  - Highly dependent on fit and user motivation and skill; foam most forgiving
  - If well fit (especially foam) can produce high level of protection
  - Sometimes one-size fits all. Sometimes come in sizes
- Earmuffs:
  - Fit over and around the ears to provide a seal against the head
  - More reliable and least training and supervision required
  - Preferable if taking on and off frequently
  - Easy to fit, but make sure user adjusts band properly
- Helmets
  - Encase the entire head (motorcycle, pilots)
  - If built in cup around ear, can be effective

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More Usage Characteristics

Issue	Earplugs	Muffs
Compatibility	Few problems	Long hair, glasses, earrings, etc. can be problem. Messes up hairstyle
Tight spaces	Few problems	Can bump against things
Monitoring	Difficult to assure used properly	Easy to tell if worn; harder to tell if worn correctly
Hot environments	May sweat in ear canals	Much worse
Cold	No problem once inserted. Hard to insert with gloves.	Provide warmth, but cushions may harden if stored in the cold. Less likely to lose; more expensive
Storage, portability, loss	Easy to carry and store. Easy to lose (but cheap, anyway)	Harder to carry and store. Can be kept on belt clip or helmet
Sabotage	Subject to puncturing, cutting, or whittling to improve comfort	Subject to band stretching, drilling holes through cup (for ventilation)
Ear wax, infection	Can't use if ear infected or wax buildup, etc.	Can use with minor ear canal infection with medical supervision

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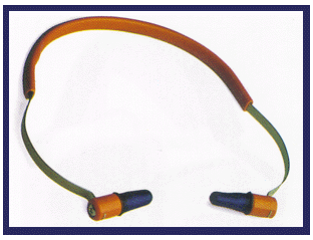
Construction and Materials for Earplugs

- Materials
  - Slow-recovery, closed-cell foam, vinyl, silicone
  - Elastomer, spun fiberglass, cotton/wax
- Types:
  - Foam
  - Moldable or formable
  - Pre-molded, custom-molded
  - Semi-insert
- Available with connecting cord, except formable
- Available in sizes for some types
  - Keep record of size for each employee
  - 2-10% will require different size for each ear
  - Sometimes limited ability to manipulate reduces choices



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Foam Earplugs

- Must roll into narrower shape
- Stay in very well. Can think inserted far enough when not
- Often made from slow-recovery PVC or polyurethane
  - PVC absorbs less moisture. Best combination of stiffness for molding and softness for comfort.
  - Polyurethane feels softer but is not more comfortable
- High density closed-cell blocks noise; does not absorb noise
- Shape is mostly cosmetic
- Disposable because of price but can be re-used because of closed cells
- Avoid handling when hands are dirty

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Inserting Foam Earplugs

Roll into narrower shape

May help to pull pinna back with other hand.

Hold with finger while expands

Should just clear the ear canal

Poor fit

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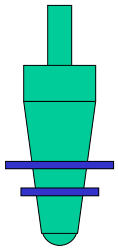
Pre-Molded

- Typically made from flexible materials, including foam.
- May have appendages to help grip during insertion.
- Have flanges to allow to fit different size ear canals.
- Flangeless more difficult to fit but do not require shaping to insert, therefore less dexterity and less cleanliness required
- Lesser noise reductions because of difficult sealing.
- Sizes
  - Males larger sizes than females
  - Whites greater than blacks



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Formable Earplugs

- Malleable materials
  - Silicone putty, cotton/wax, spun fiberglass (“Swedish wool”)
  - Not elastic
- Pack into ear canal
- Can come loose or lose seal with jaw movement
- Cotton/wax, silicon plugs – consumer market
  Silicon sticky, so good for swimmers
- Fiberglass down in polyethylene sheath good combination

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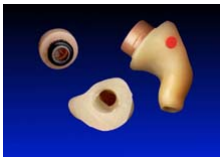
Custom Molded Earplugs

- Silicone putty; some vinyl or acrylic
- Process:
  - Make impression of ear canal by injecting viscous material or the plug material itself
  - Create mold, then pour or form the earplug unless the mold itself will be the plug
- Fills end of ear canal as well as portion of concha/pinna to hold in place
- Incorrect insertions easily detected
- Don’t come loose over time.
- Not as good protection, but very comfortable
- Like other plugs, will shrink and harden over time.
- Turn around time can be high, so substitutes must be worn until replaced.



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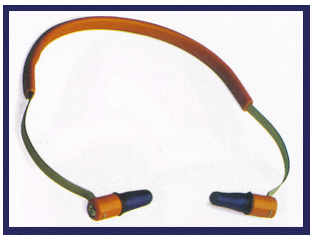
Semi-Insert Earplugs

- Soft pieces pressed against ear canal by spring-loaded band.
- More convenient than ear muffs
- Good when must be inserted and removed frequently.
- Can provide adequate protection, but may become uncomfortable over time.



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Ear Muffs

- Rigid molded plastic earcups that seal around the ear using foam or fluid-filled cushions.
- Held in place by spring-loaded headbands or short spring-loaded arms attached to a hard hat
  - For latter, harder to adjust and constant storage on hat may compress the foam material.
  - If compressed additional 20% with same force, replace.
- Sealing requires significant force.
  - Force gives greater protection, worse comfort.
- Cups are lined with acoustical materials (open-cell foam) to absorb high-frequency noise within the cup.
- Fit *nearly* all users.
  - Evaluate fit.
  - Concavities in the jaw and other features can affect fit.
  - Glasses can be problem.
- Large volume good for low freq. Small volume good for higher frequencies
  - At hi frequency, greater surface area increases vibration modes
  - Smaller easier to seal around pinna
- Fluid or foam-filled cushions work equally well, but former is more expensive and can develop leaks.
- Most important factor for attenuation is fit and proper use. Much more important than volume and other attenuation issues.

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Mechanisms and Limitations of HPD Attentuation

- Leaks
  - Poor seals
  - Broad band of frequencies passed through, but most noticeable at low frequencies
- Hearing protector vibration
  - Earplugs can vibrate within the ear canal, limiting low-frequency reduction
  - Earmuffs vibrate, also limiting low-freq reductions
- Structural transmission
  - Significant penetration or re-radiation for ear muffs, limiting reduction for freq $\geq$ 1k
- Bone and tissue conduction
  - Noise can vibrate through the skull
    - 40-50 dB attenuation
    - Hard hat and earmuffs have little effect on this
    - Helmets do

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Fitting and Issuing

- Individual and group training
- Initial ear examination
- Hygiene
- Tips for fitting

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Enforcement of Utilization

- Policies must be enforced rigorously
- Enforcement must be firm, equitable, and consistent
- Supervisors must do this and be accountable for it.
- Example progression:
  - Verbal warning: be positive
  - Written warning
  - Brief suspension without pay
  - Termination

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Measuring Attenuation

- Only a few reliable, accurate methods
- Real-ear attenuation at threshold (REAT)
  - Gold standard, except for impulse noise and devices that claim variable noise reductions
  - EPA requires
  - Basically an audiometric test with and without protector
  - Level based on median subject's threshold change
  - Different labs get different results
    - 3-8 dB for earplugs
    - 2 dB for earmuffs
  - More real-world if fit NOT supervised by experimenter (1997 method B)
- EPA labeling method highly artificial (based on 1979 test method, which controlled fitting rigorously)

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REAT: real ear attenuation tests

- Measure drop in hearing thresholds with and without hearing protectors on
- Lab-based
  - Fitting closely controlled by experimenters
- Can be field based
  - workers selected from the workplace without warning so cannot readjust HPDs

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Attenuation Characteristics of HPDs

- Differences of 3 dB are insignificant
- How inserted or applied is crucial, so
  - wide variations in reported attenuation
  - Different rank ordering by different investigators
  - Can compare only if same lab does all
- Should compare both well-fitted and “field” fitting

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Optimum Attenuation

- Most reported values are based on lab-REAT
- Over-estimates protection
- Wide degree of overlap found among HPDs
- Slow-recovery foam among best
  - 30-45 dB for ≥ 2k Hz
  - 20-40 dB for < 2k Hz
- Custom-molded more variable; similar to pre-molded and formable
- Earmuffs lowest at low frequencies and approach limits due to bone conduction at 2k Hz and above
- Foam earplugs better for less than 500 Hz and greater than 2k Hz.

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Real-world attenuation

- Usually less than half of lab findings
- Not consistent fraction
- Earplugs much greater drop than earmuffs
- EAR foam best of plugs at about 40% (see p. 421)
- Labeled NRR with subtraction of 2-SD from mean of lab-tested values (98%).
- Field values based on subtracting 1-SD from mean (84%).
- Hence, much better control possible for some individuals

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Wearing Time

- If not worn, not effective
- Effective NRR greatly reduced for NRR $\geq$ 10 dB
- Important that wear all of the time exposed

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Dual Protection

- Two better than one, but not sum of NRR.
- Use if 8-hr TWA > 105 dBA, especially if $\leq$500 Hz dominates
- At lower levels interferes with communication too much

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Infrasound/Ultrasound

- REAT usually for 125- 8k Hz
- Low frequency
  - Well-fitted insert earplugs much, much better than earmuffs, which may even amplify sounds
- High frequency
  - Ear muffs and plugs both work well

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Impulse and Weapon Noise

- Impulse difficult to estimate attenuation and hearing damage not well-characterized
- Threshold hearing shift much lower than predicted from attenuation studies
- Greater attenuation than from steady noise
- Explosions may shift earmuffs, breaking protection

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Using Attenuation Data to Estimate Protection

- Critically dependent on correspondence between real-world and test conditions
- Excessive focus on protection estimates unwarranted
- Use 5-dB ranges
- At less than 95 dBA, more important to focus on proper HPD usage

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Octave Band Method (NIOSH Method 1)

- Potentially most accurate
- At each frequency, subtract SD correction from mean
- Log-sum the results

- Most important point is that earplugs better than muffs if mostly 125-250 Hz and muffs better if 1k Hz.

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Noise Reduction Rating (NRR)

- Similar to NIOSH No. 2 method
- Uses pink noise (equal energy)

Estimated exposure (dBA) = workplace noise (dBC) - NRR

- NIOSH No. 3

Estimated exposure (dBA) = workplace noise (dBA)
- (NRR – 7 dB)

7 dB reduction is safety factor

- Errors from methods can be large, but are less than error due to reliance on lab data

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NRR(SF) – subject fit

- Proposed 1995; not a law
- Based on real-ear attenuation (fit subjects)
- Subtract 1 standard deviation instead of 2
- Typically less than NRR by 2-20 dB

Est. exp. (dBA) = Leq (dBA) – NRR(SF)

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Other rating schemes

- Single number rating
- High medium low
- Sound level conversion (SLC_{80})

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Derating HPD Attenuation and OSHA's 50% Factor

- Since NRR greatly overestimates reduction, OSHA "derates" protection values by 50%.
- If used, apply also when using octave band data
- Not applicable when determining compliance with hearing protection requirements (to the confusion of all)

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Effects of HPDs on Auditory Perception

- Attenuation varies with frequency
- Understanding speech
  - Own voice sounds different: low frequencies amplified, other frequencies of own voice sound just as loud, so speaker thinks louder than really is. Must learn to speak louder than seems necessary
  - Cannot remove unwanted sound without also removed wanted sound in same frequencies
  - Since not same across all frequencies, can sound muffled
  - On the other hand, can hear speech better if used in high-noise because reduces overall level, reducing distortion effects in cochlea contributed by excessive noise (reduced “acoustical glare”)
  - Result, for computed attenuation of:
    - < 70 dBA: worse
    - 80-85 dBA: no effects
    - > 85 dBA: better, depending on signal to noise ratio
  - Therefore, aim for 70-85 dBA after attenuation

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Effects of HPDs on Auditory Perception

- Understanding speech - continued
  - For hearing impaired, complex but:
    - Decrease for low to moderate noise levels
    - Reduction lessened for higher noise levels
    - Complex because attenuation may reduce sound to below their thresholds in the speech frequencies.
- Experienced workers use visual cues and learning to do better than non-experienced in noisy environment

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Effects of HPDs on Auditory Perception

- Responding to Warning and Indicator Sounds
  - Similar to effects on understanding speech
  - Harder to notice if higher background sound
  - Research, subtle warning sounds (clink):
    - No effect of HCP if expecting sound
    - Reduced perception if distracted
  - Research, intentional warning sound (horn)
    - No effects
    - Should have warning sounds < 2k Hz for hearing impaired
- Localization
  - Cannot learn to compensate
  - Ear muffs greater effect
  - Not clear: ability to determine distance of sound

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Auditory Perception: General Remarks

- For non-hearing impaired, effects mostly positive with minimal negative effects
- For hearing impaired, careful consideration needed
  - Ideal solutions elusive
  - Should try to augment warning and indicator sounds or replace them with tactile indicators
- If noise intermittent
  - HPDs interfere with speech during quiet periods
  - Therefore, use ear muffs since easily removed
  - Amplitude sensitive devices may work better for low levels but interfere more at high levels

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Specialized HPDs and Other Devices Which Block Sound at the Ear

- Flat frequency HPDs designed to reduce frequency distortion
  - Have small “leak” (orifice)
  - Work better than others for ≤ 90 dBA
  - On the other hand, offer less protection if high-frequency noise predominates

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Specialized HPDs and Other Devices Which Block Sound at the Ear - continued

- Amplitude-Sensitive HPDs
  - “level-dependent”: attenuation increases with SPL
  - Have non-linear component, such as valve, diaphram, or sharp-edged orifice or narrow opening: works because low-intensity noise have laminar airflow through openings
  - Threshold very high for increased attenuation: 110-120 dB, so best only for impulsive blasts or gunfire
  - Vented earplugs provide weak protection at ≤ 1 k Hz
  - Exception is orifice-type earmuff that provides 25 dB protection from 400- 8000 Hz

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Specialized HPDs and Other Devices Which Block Sound at the Ear

- Active Hearing Protectors
  - Amplitude Sensitive Sound Transmission HPDs
    - Use microphones and amplifiers to transmit external sounds
    - Can control to desired level (e.g., 85 dBA)
    - Limit is due to direct transmission overwhelming plug or muff
    - May introduce high frequency distortion
    - May be best for impulsive noise
  - Active Noise Reduction
    - Destructive interference (180 deg) to remove noise
    - Works best for relatively invariant continuous noise less than 1 k Hz

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Specialized HPDs and Other Devices Which Block Sound at the Ear

- HPDs with Communication Features
  - Earphones built in for communication
  - Wireless FM or infrared
  - Should limit sound level delivered to ear
- Hearing-Aid Earmolds
  - Most hearing aids provide inadequate protection when turned off (must be off!)
  - However, unvented earmolds and foam earplugs work well
- Recreation earphones
  - Dismal noise attenuation compared to HPDs
  - May increase output of sound, producing higher exposures (Royster found only 2 dBA increase for most, but > 90 dBA for 20% of workers)
  - Prohibit if SPL > 90 dBA
  - Problematical if 85-90 dBA

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HPD Standards, Regulations and Related Documents

- ANSI S12.6-1997 specifies real-ear tests of HPDs
- EPA labelling
  - Noise Control Act of 1972
  - Specified testing with ANSI S3.19-1974
  - NRR
  - Low budgets led EPA to abolish testing and revoke product verification testing
  - However, original NRRs still used
  - Virtually all professionals recommend use of NRR(SF), but EPA has not acted

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International Standards and Regulations

- International Organization for Standardization (ISO)
  - Developed REAT measurements
  - Draft documents on earplugs and earmuffs

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Recommendations

- Fitting, issuing, training, and motivation most important
- For TWA < 95 dBA, virtually all devices are adequate if fit and worn correctly
- For TWA > 95 dBA, use ear muffs or foam earplugs
- For TWA > 105 dBA, use both
- Large study found that issuing more effective protectors had no effects on hearing reduction

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The End

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