Canal segment length of custom earplugs: Effects on attenuation (and comfort)

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ACKNOWLEDGMENT

This study was funded by the Office of Naval Research.
Can you get TOO MUCH attenuation from an HPD?

- Of course, the answer is YES...
- But the answer could change, depending on the environment...
• **Very high attenuation is desirable** in some extreme occupational or operational environments
  • Aircraft carrier flight deck: ~130-150 dBA
  • Aircraft cockpit: ~110-130 dBA

• **Sufficient attenuation is not easily obtainable** in these environments
  • Factors related to HPD design and/or manufacture
  • Factors related to the wearer
Custom-molded earplugs (CMEPs)

http://www.westone.com/hhc/index.php/about/military

- Critical factors for achieving high attenuation:
  - Airtight seal in the ear canal (e.g., Pirzanski et al., 2000)
  - Longer canal segment (e.g., Du et al., 2008)
Attenuation in CMEPs

- Norris et al. (2011): attenuation increased with CMEP canal segment length up to a length of 15 mm (which is past the 2\textsuperscript{nd} bend)
  - Anatomically correct test fixture
  - Set of CMEPs

- Berger (1983): attenuation increased with foam plug insertion depth at frequencies $\leq 1000$ Hz
Attenuation in CMEPs

- Canal segment lengths that extend past the 2nd bend may cause discomfort for some people (Pirzanski, 1997)

http://store.treoo.com/main/services/ear-impressions.html
In extreme environments, the goal is to achieve maximum attenuation while maintaining wearability

• What we know:
  • Longer canal segment length increases attenuation, but may decrease comfort

• What we don’t know:
  • The forms of the functions relating attenuation and comfort to canal segment length
  • The variability of these functions across individuals
In the current study...

- We mapped the form of the function relating attenuation to CMEP canal segment length in four individuals
  - Within-subjects design
- We obtained anecdotal reports of comfort
Participants

- Two men, two women
  - Mean age = 24.8 yr; SD = 0.5
  - Audiometrically and otologically normal
Custom earplugs

- Manufactured by Westone Laboratories, Inc.
- Solid silicone
- Canal segment extended past second bend
Earplug attenuation measurement

- Monaural sound-field hearing thresholds measured for 1/3-octave noise bands
  - Center frequencies: 125 - 6300 Hz
  - Test ear alternately occluded and unoccluded
  - Non-test ear occluded with a foam plug + earmuff
- Attenuation (in dB) =
  \((\text{occluded threshold}) - (\text{unoccluded threshold})\)
Procedures

- Each subject visited the lab seven times
- At each visit...
  - Attenuation measured for 4 fittings of the CMEP
  - Subject was asked if CMEP was comfortable
  - Canal segment of CMEP shortened by 2 mm
Earplug modification

Buffalo V35 Handpiece System with a blue grinding stone.
RESULTS (Averaged data)
Attenuation decreased as CMEP canal segment length was shortened.

The effect was greater for low-mid frequencies (\( \leq 1000 \text{ Hz} \)) than higher frequencies (\( > 2000 \text{ Hz} \)):
- Median decrease in lows = 25 dB
- Median decrease in highs = 10 dB
Effect of canal segment length

Real-Ear Attenuation (dB)

Frequency (Hz)

10-12 mm removed  6-8 mm removed  2-4 mm removed  Full length
Effect of canal segment length/insertion depth

- 0% insertion: 10-12 mm removed
- 15-20% insertion: 6-8 mm removed
- 30-60% insertion: 2-4 mm removed
- 80-100% insertion: Full length

Solid = foam plug, Berger (1983)
Dashed = custom plug, Tufts (2014)
RESULTS (Individual data)
• Decrease in attenuation was not linear

• Some regions in the ear canal were more critical for maintaining attenuation than others
Subject 1 (Male)

Personal Attenuation Rating as a function of canal length

Canal segment length (mm)

PAR (dB)

Visit 1 2 3 4 5 6 7

Transverse view of earplug
Subject 1 (Male)

- **Frequency (Hz)**: 125, 250, 500, 1000, 2000, 3150, 4000, 6300
- **Attenuation (dB)**: 0, 10, 20, 30, 40, 50, 60

- Thicknesses: 17 mm, 15 mm, 13 mm, 11 mm, 9 mm, 7 mm, 5 mm

Graph shows attenuation levels across different frequencies for various thicknesses.
Subject 2 (Female)

Personal Attenuation Rating as a function of canal length

Visits 1234567

Canal segment length (mm)

PAR (dB)

Transverse view of earplug
Subject 2 (Female)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3150</th>
<th>4000</th>
<th>6300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attenuation (dB)</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

- 15 mm
- 13 mm
- 11 mm
- 9 mm
- 7 mm
- 5 mm
- 3 mm

Frequency (Hz) vs. Attenuation (dB)
Subject 3 (Male)

Personal Attenuation Rating as a function of canal length

Visit 1 2 3 4 5 6 7

Canal segment length (mm)
Subject 4 (Female)

Personal Attenuation Rating as a function of canal length

Transverse view of earplug
Subject 4 (Female)

Frequency (Hz)

125 250 500 1000 2000 3150 4000 6300

Attenuation (dB)

0 10 20 30 40 50 60

18 mm
16 mm
14 mm
12 mm
10 mm
8 mm
6 mm

Frequency (Hz)

125 250 500 1000 2000 3150 4000 6300

Attenuation (dB)
DISCUSSION
Discussion

- Location of critical regions:
  - Between 1st and 2nd bends
  - At or near 2nd bend

- Comfort was achieved without removing critical regions

- However, for the two females, some attenuation had to be sacrificed to achieve comfort
Discussion

- Accounting for individual variation in location of critical regions and in comfort
  - Did snugness of fit vary along the canal segment length?
  - Would an acclimation period have changed comfort judgments?
DIRECTIONS FOR FUTURE STUDY
Modeling the effects of canal segment length on attenuation

- Control/characterize variability
  - Control snugness of fit along length of canal segment
  - Characterize ear canal size and geometry
    - E.g., Abel et al. (1990)
  - Measure comfort more formally (including an appropriate acclimation period)
    - E.g., Byrne et al. (2011), Davis (2008)
THANK YOU FOR YOUR ATTENTION

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