National Hearing Conservation Association
Dallas, Texas.

Panel Discussion: HPD Attenuation Verification: A Viable Option?

Jeremie Voix's Presentation Abstract

To address the issues related to the field performance of HPD, a new concept has been developed using a re-usable earplug that is custom-fitted by injecting silicon between a hard inner core and a soft expandable envelope. A miniature bore in the hard core is used to determine the sound pressure level difference (noise reduction) across the earplug. The benefits of this measuring capability are the real time monitoring of the acoustic seal during the injection process - until an adequate fit has been reached - and the development of a field method to estimate the noise attenuation obtained by such expandable earplugs as worn in the workplace. This estimation method uses a statistical approach to link subjective attenuations with objective measurements of the noise reduction. The support of Sonomax Hearing Health Inc., IRSST (Quebec Occupational Health and Safety Research Institute) and NSERC (Natural Sciences and Engineering Research Council of Canada) is gratefully acknowledged.
HPD Attenuation Verification: A Viable Option?

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University of Quebec

Jean Zeidan

Sonomax Hearing Healthcare Inc.

Quebec Occupational Health and Safety Research Institute

Natural Sciences and Engineering Research Council of Canada
Introduction

• A need for objective measurement devices
Introduction

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• Ideas on how to do it
  - «IL and NR are two equivalent quantities for assessing the objective protections of earmuffs »

Introduction

• A need for objective measure devices

• Ideas on how to do it
  - «IL and NR are two equivalent quantities for assessing the objective protections of earmuffs »*

• Let's do it...

The Setup

- Expandable Earplug
- External Microphone
- Internal Microphone
- Reference Sound Source

Injection Process → Curing Phase → Performance Tests → Filter Selection
Basic Relationships

\[ TFOE = 20 \log_{10} \left( \frac{p_3}{p} \right) \]
\[ IL = 20 \log_{10} \left( \frac{p_3}{p'} \right) \]
\[ NR_0 = 20 \log_{10} \left( \frac{p}{p_3} \right) \]

\[ IL = NR_0 + TFOE \]
Basic Relationships (…continued)

\[ IL = NR_0 + TFOE \]

Practically:

\[ NR = 20 \log_{10} \left( \frac{p'_0}{p''_2} \right) \]

\[ REAT = IL + PN \]

\[ REAT = NR + TFOE + 20 \log_{10} \left( \frac{p''_2}{p'_2} \right) + 20 \log_{10} \left( \frac{p'_2}{p'_3} \right) + 20 \log_{10} \left( \frac{p}{p'_0} \right) + PN \]

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Measurements

Visual Inspection

Audiogram 1

x 10 subjects*, 3 trials*, 2 ears

Injection Process

Questionnaire

Audiogram 2

*ANSI S3.19
ISO 4869
ANSI S12.6... to follow
Compensation Calculation (1/3)

Octave Band Compensation:

\[ COMP^i = REAT^i - NR^i \]

where \( NR^i \) is the Equivalent Binaural Noise Reduction:

\[ NR^i = \begin{cases} 
NR^i_L & \text{if } (NR^i_L + A^i_L - A^i_R) \leq (NR^i_R + A^i_R - A^i_L) \\
NR^i_R & \text{else}
\end{cases} \]

Overall Compensation:

\[ COMP = 10 \log_{10} \sum_{i=1}^{7} \frac{100}{10} - 10 \log_{10} \sum_{i=1}^{7} \frac{100 - (REAT^i - NR^i)}{10} \]
Compensation Calculation (2/3)

Distribution of Compensation Freq. 125
\[ N (3.8; 5.64) \]

Distribution of Compensation: Freq. 250
\[ N (0.9; 4.45) \]

Distribution of Compensation : Freq. 500
\[ N (-1.8; 5.45) \]

Distribution of Compensation :Freq. 1000
\[ N (-1.5; 4.01) \]

Distribution of Compensation: Freq. 2000
\[ N (17.8; 5.75) \]

Distribution of Compensation:Freq.4000
\[ N (27.1; 4.4) \]

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## Compensation Calculation (3/3)

<table>
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<tr>
<th></th>
<th>Comp125</th>
<th>Comp250</th>
<th>Comp500</th>
<th>Comp1000</th>
<th>Comp2000</th>
<th>Comp4000</th>
<th>Comp8000</th>
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<td>30</td>
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<td>27</td>
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<td>Mean</td>
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<td><strong>Most Extreme</strong></td>
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<td>Absolute</td>
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<td>.102</td>
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<td>.071</td>
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<td>.086</td>
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<td>.386</td>
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<td>.699</td>
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<td>Asymp. Sig. (2-tailed)</td>
<td>.712</td>
<td>.916</td>
<td>.996</td>
<td>.998</td>
<td>.853</td>
<td>.712</td>
<td>.751</td>
<td>.979</td>
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</table>
P-PAR Computation (Predicted Personal Attenuation Rating)

Noise Reduction Rating*:

\[ NRR = 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + C_i}{10}} - 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + A^i - \hat{REAT}^i}{10} + 2 \sigma_{REAT}^i} - 3 \]

Personal Attenuation Rating:

\[ PAR = 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + C_i}{10}} - 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + A^i - \hat{REAT}^i}{10}} \]

Estimation of the \( \hat{REAT} \):

\[ \hat{REAT}^i \equiv NR^i + N(COMP^i, \sigma_{COMP}^i) \]

Predicted Personal Attenuation Rating:

\[ P \cdot PAR = 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + C_i}{10}} - 10 \log_{10} \sum_{i=1}^{7} 10^{\frac{100 + A^i - \hat{REAT}^i}{10}} \]

*Slightly modified to get rid of 3150 Hz and 6300 Hz bands
P-PAR Computation
The Performance Tests

Seal Test
Rating Test
Protection Test
Seal Test

- Goal:
  - Make sure that the earplug fits properly and thereby is providing a good acoustic seal.

Details:
Check that the user belongs to the 98% percentile of NR values at 250 Hz obtained during ANSI S3.19 tests.

\[
\text{Status} = \begin{cases} 
\text{pass} & \text{if } NR_{250\text{Hz}} \geq 9\text{dB} \\
\text{fail} & \text{else}
\end{cases}
\]
Rating Test

• Goal:
  - Make sure that the earplug offers at least the NRR value. This ensures that the earplug really does not need to be derated.

Details:
Check that the user belongs to the 98% percentile; i.e. That the P-PAR (at 84% confidence) is over the published NRR.

\[
\text{Status} = \begin{cases} 
\text{pass} & \text{if } P \cdot \text{PAR}_{84\%} \geq 15\text{ dB} \\
\text{fail} & \text{else}
\end{cases}
\]
Protection Test

• Goal:
  - Verify what protection the earplug offers and adapt this amount of protection to match the user's needs.

Details:
  Predict the PAR of the earplug and adapt it by using specific dampers and checking what the protection outcome is.

Standard: CSA Z94.2-2002

<table>
<thead>
<tr>
<th>Sound level resulting from the use of the protector (dBA)</th>
<th>Protection outcome</th>
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<tbody>
<tr>
<td>85 +</td>
<td>Insufficient</td>
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<tr>
<td>80–85</td>
<td>Acceptable</td>
</tr>
<tr>
<td>75–80</td>
<td>Optimal or Ideal</td>
</tr>
<tr>
<td>70–75</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Less than 70</td>
<td>Overprotection</td>
</tr>
</tbody>
</table>

How?
Concurrent & Future Work
Concurrent

- Analytical Model of Earplug
  - Discrete
  - Continuous 1-D
Concurrent & Future Work

• Analytical Model of Earplug
  – Discrete
  – Continuous 1-D

• Analytical "Retro-Computation" of Transfer Functions
  – Parametric Identification
  – Analytical Computation of Transfer Functions... for filtering solutions!
Concurrent & Future Work

• Analytical Model of Earplug
  – Discrete
  – Continuous 1-D

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  – Analytical Computation of Transfer Functions... for filtering solutions!

• Filtering solutions: “Flat”, “Smart”...
Conclusion

• Scientifically/Technically
  • Statistical relationships between NR and REAT
  • Analytical model of all TF... for this earplug
Conclusion

• **Scientifically/Technically**
  - Statistical relationship between NR and REAT
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• **Practically**
  - Hardware and Software Solutions have been developed for field validation of HPD's performances (seal, rating and protection tests)
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  - ABSOLUTELY... for this earplug!
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• Practically
  • Hardware and Software Solutions have been developed for field validation of HPD's performances (seal, rating and protection)

• A Viable Option?
  • ABSOLUTELY... for this earplug!
  • POSSIBLY... for all other products with a sound bore
References


Biographical Sketch

- Jeremie Voix, ing., M.Sc.A.

- Jeremie Voix is an Acoustic Engineer with field experience in industrial noise reduction projects. He holds a Bachelor of Physics from University of Lille (France) and a Master of Applied Sciences in Acoustics from Sherbrooke University (Canada). He is currently finishing his Ph.D. at the University of Quebec (Ecole de Technologie Supérieure). His work is part of a Collaborative Research & Development project granted by the Natural Sciences and Engineering Research Council of Canada (NSERC) between the University and Sonomax Hearing Health Inc for the development of a « smart » earplug.