To Measure the Impact of Hearing Protectors on the Perception of Speech - The Challenges and a Proposal

Per Hiselius, Ph.D. - 3M | Sweden
The Question

• The ability to communicate verbally is important.
• Hearing Protection Devices (HPDs) are likely to affect this ability.

Question: To what extent will a specific HPD affect the ability to communicate?
Available methods

• Predictions based on information regarding levels and thresholds, e.g. SII.

• Predictions based on objective measurements, e.g. STI (RASTI/STIPA).

• Counting number of correctly perceived words/sentences using test subjects, e.g. MRT, Quick-SIN, Hint etc.

What about experienced ‘ease of understanding’ and perceived quality? Mean Opinion Scores (MOS)
Available methods

SII, Speech Intelligibility Index (Artikulation Index, AI)
STI, Speech Transmission Index (RASTI: Room Acoustics STI, STIPA: STI for Public Address)
PESQ, Perceptual Evaluation of Speech Quality
3QUEST, 3-fold Quality Evaluation of Speech in Telecommunications
MRT, Modified Rhyme Test
DRT, Diagnostic Rhyme Test
Quick-SIN, (Quick) Speech In Noise
Hint, Hearing In Noise Test
PB, Phonetically Balanced word lists
CVC, Consonant-Vowel-Consonant word lists
CAT, Callsign Acquisition Test
and many more...

Per Hiselius, NHCA 2014
Reinventing the wheel?

Many excellent methods already available!

Is there really need for one more?

...that depends on what you are looking for...
Speech Intelligibility in noise - The Basics

- Speech levels vs. hearing threshold.
- Speech vs. background noise (incl. reflections/reverberation).
- The importance of S/N varies across the frequency range.
- Auditory masking may affect the results.
- Quality of speech signal (*may get distorted along the way*)
- Redundancy in speech (*+other clues, e.g. context of situation, visual clues*)
Speech Intelligibility in noise - The Basics


Per Hiselius, NHCA 2014
Speech Intelligibility in noise - The Basics


Per Hiselius, NHCA 2014
Many excellent methods already available!

Is there really need for one more?

...that depends on what you are looking for...


Per Hiselius, NHCA 2014
What am I looking for?
To measure how HPDs affect the ability to understand speech in noisy environments.

- Fast
- Convenient
- Fully automated, self administered
- High precision
- Possible to reuse test subjects many times and often
- Easy to implement
- Possible to use globally with same speech content
- Stable between labs
- At least two different types of background noise
- Easy to interpret the results
- Also to be used for up-link (sending direction)
- Relevant!
A Proposal

Measure the *speech reception threshold*, *SRT*, in noise using CAT speech material at a level corresponding to a *raised voice* - 2*std*, and by adjusting the noise level using a Bekesy tracking procedure⁶.

Measure once while using the device - and once without using it.

Present the difference, i.e. to what extent the ability to understand the speech signal was affected.

*The lowest level at which the speech content can be understood
⁶ A ‘step by step’ procedure, i.e. not a continuous change of the noise level.

Per Hiselius, NHCA 2014
A Proposal

<table>
<thead>
<tr>
<th>Alpha</th>
<th>A</th>
<th>Oscar</th>
<th>O</th>
<th>One</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bravo</td>
<td>B</td>
<td>Papa</td>
<td>P</td>
<td>Two</td>
<td>2</td>
</tr>
<tr>
<td>Charlie</td>
<td>C</td>
<td>Quebec</td>
<td>Q</td>
<td>Three</td>
<td>3</td>
</tr>
<tr>
<td>Delta</td>
<td>D</td>
<td>Tango</td>
<td>T</td>
<td>Four</td>
<td>4</td>
</tr>
<tr>
<td>Echo</td>
<td>E</td>
<td>Victor</td>
<td>V</td>
<td>Five</td>
<td>5</td>
</tr>
<tr>
<td>Foxtrot</td>
<td>F</td>
<td>Whiskey</td>
<td>W</td>
<td>Six</td>
<td>6</td>
</tr>
<tr>
<td>Hotel</td>
<td>H</td>
<td>X-ray</td>
<td>X</td>
<td>Eight</td>
<td>8</td>
</tr>
<tr>
<td>Kilo</td>
<td>K</td>
<td>Yankee</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lima</td>
<td>L</td>
<td>Zulu</td>
<td>Z</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Speech content from the “Callsign Acquisition Test”, CAT.

I decided to use random pairs from the list, e.g. “Oscar, Tango” or “Four, Echo”.

Per Hiselius, NHCA 2014
A Proposal - Pros & Cons

Con:

Limited word material, and only single words, will not cover all aspects of speech.

Possible to identify words at very low S/N. The noise levels may therefore become rather high.

S/N may reach -20 dB!
A Proposal - Pros & Cons

Pro:

*Realistic (raised) speech level,*
Will not primarily be testing the hearing threshold of the test subject.
Required for communicational devices (level dependent, 2-way radio, etc.)

*Few and known words (from CAT),*
Works globally
Very steep learning curve => can reuse test panel
Few words gives less variation and thus allows for a fast test
SRT + steep psychometric function provides high precision
Can use standard (or slightly modified) keyboard for providing answers

*Focus on the difference (measure w & w/o device),*
Minimizes variations due to individual differences
Less dependent on speech material
Less dependent on lab facility (speakers, acoustics of test lab, etc.)
Shows the impact of the device (*how much higher/or lower the noise level must/can be when the devise is used*), i.e. a measure which can be interpreted!
As promised: Some initial results!

Learning effect for five test subjects over 5 consecutive days

Day 1  Day 2  Day 3  Day 4  Day 5  Day 5 + 2 weeks!

Normalized levels with offset, dB

Test # 1 - 30

Individual Standard Deviation ≈ 0.7
Entire group ≈ 0.9

Per Hiselius, NHCA 2014
Conclusions:

Method meets all my requirements - so far...

S/N is the key parameter, as expected.

The impact of low attenuation HPDs seem to be very small for most people - but not for all...

Any feedback on my proposal is most welcome!
The Procedure

Two random words from the CAT presented in either of two noises

*Speech*: Raised voice - 2*std

*Speech*: 50/50 mix of Male and Female frequency spectrum

*LowFrequency noise*: pink noise + brown noise (mixed at equal RMS level)

*HighFrequency noise*: pink noise + white noise (mixed at equal RMS level)

Both words correctly identified on keyboard => the noise level is increased
Both words not correctly identified on keyboard => the noise level is reduced

Amount of noise level change is random (within defined range)

To avoid excessive levels:

*Noise only when speech is presented*

*Words presented with a (slight) random delay*

*To increase level, two rounds of words need to be correct, i.e. 2+2 words!*

Per Hiselius, NHCA 2014
Speech Intelligibility in noise - The Basics

*If you can’t hear it you can’t understand it. Obvious and trivial, right?*

- Hearing thresholds vary greatly between individuals.
- Auditory masking vary greatly between individuals.
- Complexity of speech (level, frequency content, dynamics).
- Languages, dialects, pronunciation, articulation.
- Two ears - directionality.

Human capacity for “filling in the gaps”

- Redundancy of information in speech signal.
- Context of situation.
- Visual clues.
- Closed set of wordscmds/commands/phrases or unpredictable, or nonsense.
- Intelligibility vs. sound quality or ”ease of understanding”.

Per Hiselius, NHCA 2014
The Quest

To find a *convenient* and *relevant* method...

...to assess the impact of HPDs on the ability to perceive and understand speech.

- Learn more about how HPDs affect the ability to perceive speech.
- Develop devices better suited for verbal communication.
- Compare devices when selecting what device to use/recommend.
As promised: Some initial results!

Bekesy tracking for three test subjects

Changes of noise level (Bekesy tracking)