New approaches to measuring hearing aid outcomes

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WHY DO WE NEED TO HAVE NEW OUTCOME MEASURES?
WHICH OPTION FILLS YOUR HUNGER?

WHICH OPTION WOULD YOU CHOOSE?
OUR DEMANDS INCREASE AS OUR STANDARD OF LIVING IMPROVES

Does it look appetizing and fill your hunger?

Does it fill your hunger?

Does it give you a total food experience?  
(Appetizing food and filling hunger is expected)
IN OUR FIELD, WE EXPECT A GOOD HEARING AID IS MORE THAN JUST **MAKING SOUNDS AUDIBLE**

Can you hear well with it?
Can you understand speech well with it in typical environments?
Can you understand speech well with it in multiple environments?
LISTENING EFFORT IS THE LATEST INCREMENTAL CRITERION

Can you understand speech well with hearing aids in multiple environments with minimal effort?
LISTENING EFFORT MAY REFLECT DIFFERENCES WHEN SPEECH INTELLIGIBILITY DOES NOT

Repeat plateaues; effort decreases as SNR increases.
SO HOW HAVE PEOPLE USED THE CONCEPT OF LISTENING EFFORT?

• Demonstrated that specific listening tasks require effort, e.g., hearing in quiet versus hearing in noise

• Demonstrated that hearing aids reduce listening effort

• Demonstrated that specific hearing aid features such as noise reduction and directional microphones reduce listening effort with or without concomitant improvement in speech understanding
I CAN JUST TELL ....

HOW do we measure listening effort?
METHODS OF MEASURING LISTENING EFFORT

• Physiological measures
  • Brain activities
    • Magnetic electroencephalography (MEG)
    • Evoked response potentials
    • Alpha power in EEG
    • fMRI
  • Autonomic nervous system
    • Pupilometry
    • Cardiac responses – heart rate variability (HRV)
    • Skin conductance
    • Hormonal responses – cortisol, chromogranin, alpha-amylase (biomarker for stress)

• Cognitive behavioral measures
  • Working memory
  • Attention
    • Selective attention – speech in noise tasks
    • Divided attention – dual tasks
    • Speed of processing – reaction time
  • Subjective ratings of listening effort, fatigue or stress
  • Tolerance of noise – such as acceptable noise level (ANL), tolerable time
METHODS TO MEASURE LISTENING EFFORT – TRACKING OF NOISE TOLERANCE (TNT)

- Continuous speech at 82 dB SPL
  - Not too loud
  - Note understanding > 80%
- Noise
  - Babble or continuous
  - Front or back
- Criterion
  - Max level of noise that can put up with while understanding > 80% of words
- Subjects track noise level, test terminates when criterion met
RATIONAL FOR TRACKING OF NOISE TOLERANCE (TNT) TEST

- Minimizes variability in loudness judgment
- Higher tolerance for noise (keeping reasonable speech) =
  - less effortful listening,
  - can stay in noise longer (if desired),
  - be satisfied in more loud noisy situations
  - greater overall satisfaction with hearing aids (than those who tolerate less noise)
- May reflect individual’s ability to inhibit irrelevant stimuli (Acceptable noise level and sensory gating, Wathen et al, poster at AN, 2017)
- Changes in the tolerable noise level between different aided conditions reflect changes in listening effort as a result of amplification
Key observations

- Aided tolerance with omni mic is poorer than unaided
- NR in DREAM and UNIQUE improved noise tolerance by 3 dB
- NR is stabilized soon in UNIQUE than in DREAM
- Directional mic > omni mic by about 5 dB
- Dir mic + NR improved noise tolerance by about 9 dB over omni alone
- Noise tolerance by UNIQUE (dir +NR) wearers is similar to normal hearing listeners under this test condition (continuous noise and spatial separation of speech and noise)
- Kuk et al (2017) JAAA
**TNL AND NUMBER OF SATISFIED LOUD NOisy SITUATIONS**

Higher TNL, greater number of loud noisy situations satisfied

Appears a TNL > 75 dB SPL (or TNT of 7 dB) is needed for satisfaction in one or more loud noisy situations

Acknowledgement: Davidson Hearing and Marco Hearing (Canada) helped in data collection
PEOPLE WITH HIGHER TNL MAY HAVE BETTER SPEECH IN NOISE SCORES

<table>
<thead>
<tr>
<th>Context</th>
<th>Repeat in Noise (% Correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Good TNT</td>
</tr>
<tr>
<td>Low</td>
<td>Poor TNT</td>
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</tbody>
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TNT Median Split (73.57 dB SPL)

<table>
<thead>
<tr>
<th>ORCA-NST Condition</th>
<th>Consonant Identification (% Correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>High</td>
</tr>
<tr>
<td>65</td>
<td>Low</td>
</tr>
<tr>
<td>80</td>
<td>Split</td>
</tr>
</tbody>
</table>

High

Low
HOW MAY TNT BE HELPFUL?

• Identify patients who may be especially sensitive to loud sounds
• Compare patient’s aided noise tolerance to normal hearing individuals (babble = 80 dB; continuous = 77 dB)
• May allow prediction of listener satisfaction and speech recognition in loud noisy places (> 75 dB for babble)
• Demonstrate the benefits of hearing aids and noise reduction systems – *improvement in TNL is reduction of listening effort*
• Future studies
  • Possible correlation between TNT and auditory inhibition and performance in noise
  • Prediction of overall satisfaction (needs to expand subject sample)
WORKING MEMORY AND LISTENING EFFORT

- Working memory (normal effort)
- Working memory (increased effort)
WORKING MEMORY YIELDS MORE INFORMATION THAN JUST LISTENING EFFORT

Phonological information (multi-modal) → Auditory scene analysis

Source – e.g., accented speech
Transmission – e.g., hearing aids, room acoustics
Listener – e.g., age, APD, HL
Message – e.g., familiarity
Context – e.g., visual, knowledge

Does it match with phonological representation in LTM (automatic, implicit processing)?

Yes → Understand and Action

No → Go to explicit, top down processing

Requires attention, effort & motivation

Good working memory

EFFORTLESS HEARING

Poor working memory

requires attention, effort & motivation
WHY IS MEASURING WORKING MEMORY INFORMATIVE?

• Variability among individuals, especially as we age
  • WM correlates with reading comprehension, and speech in noise ability

• For patients
  • Better understanding the reasons for difficulty

• For professionals
  • Another means of outcome measure
  • May help clinicians select more optimal form of amplification
  • May help guide rehabilitation

• For hearing aid manufacturers
  • Design more effective algorithms (*Effortless Hearing* design rationale) and offer customized fitting guidelines (e.g. AE)
The French tourists had to choose between traveling to England by train or by boat.

These children grew up with a mother, who was suffering from a severe illness.

Her boss told her, she couldn't have a day off without giving a very good reason.

It's unbelievable what she can do with only a paper and a pencil.

This guy is a stubborn mule and for him it's impossible to accept an excuse.

The prime minister looked very cheerful during the opening of the new factory.
NOW, **RECALL** THE LAST WORD OF EACH SENTENCE
IN ANY ORDER

- **BOAT**
- **ILLNESS**
- **FACTORY**
- **EXCUSE**
- **REASON**
- **PENCIL**
THE READING SPAN TEST – HOW WORKING MEMORY HAS BEEN MEASURED

• Sets of 2,3,4,5,6 sentences on screen
• Recall last word of sentence after each set

Daneman and Carpenter, 1980
van den Noort et al, 2008
A PARTIAL LIST OF WORKING MEMORY TESTS

- Woodcock Johnson Cognitive Test battery (Woodcock et al, 2001)
- Digit Span (forward and backward) on Wechsler Adult intelligence Scale (Wechsler 1997)
- Reading Span Test (Daneman & Carpenter, 1980; Ronnberg et al, 1989; van den Noort et al, 2008)
- Listening Span (Pichora-Fuller et al, 1995)
- Sentence final Word Identification and Recall (SWIR, Ng et al, 2013, 2015)
- Cognitive Spare Capacity test (CSCT, Mishra et al 2013, 2104)
- Auditory Inference Span test (AIST, Ronnberg et al, 2011, 2014)
- Simon Says measures (Humes & Floyd, 2005)
- N-back test (Jaeggi et al, 2010)
- Word Auditory Recognition and Recall Measure (WARRM, Smith et al, 2016)
TEST OF WORKING MEMORY IS NOT THE SAME AS TEST OF COGNITIVE IMPAIRMENT
AN AUDIOLOGY-BASED, ECOLOGICALLY RELEVANT WORKING MEMORY TEST IS NEEDED

• We are hearing healthcare professionals interested in auditory functions

• Daily verbal communications are
  • Topic focused with content – within sentence and between sentence contextual cues
  • Sentences are reasonable length with sufficient pauses
  • Motivation driven (gives up if too effortful)
  • Quiet and noise backgrounds – and realistic levels and SNR
  • So results may be more reflective of daily difficulties
THE REPEAT-RECALL TEST (RRT) - TEST CONSTRUCTION

• Two versions – high context (meaningful, semantic list) and low context (non-meaningful, syntactic list).

• High context - 5 topics (food and cooking, movies and books, music, shopping, sports), each consisting of 7 sets of 6 natural sentences

• Each set of sentences is to be used at one signal-to-noise ratio (0, 5, 10, 15 and quiet).

• Each set of 6 sentences has 20 target words

• Each sentence is between 6 and 8 words

• Speech is presented at 75 dB SPL. Noise is 8-talker babble from same azimuth (0°)
THE REPEAT-RECALL TEST – HIGH CONTEXT

• Example of **High context (semantic list)** – each sentence is meaningful and related to other sentences (same topic) in list

  • Keep the **ice cream** in the **freezer**.
  • The **chef cooks** food in a **restaurant**.
  • The **barbecue grill** used **hickory wood**.
  • **Wash** the **fruit** in the **sink**.
  • The **tart pie** had too much **lemon**.
  • He tried **new foods** in **different countries**.
THE REPEAT-RECALL TEST – LOW CONTEXT

• Example of low context (syntactic list) – each sentence has same structure as high context list but meaningless; formed by moving key target words (nouns, verbs) around sentences.

• Keep the ice foods in the lemon.
• The cream cooks food in a country.
• The barbecue chef used hickory freezer.
• Wash the grill in the restaurant.
• The tart fruit had too much wood.
• He tried new pie in different sinks.
THE ORCA-RRT TEST FLOW

Repeat each sentence
Recall all 6 sentences
Rate effort level & tolerable time
Display results

ONE SNR BY CONTEXT CONDITION
(Takes two minutes)
AVAILABLE INFORMATION AFTER RRT

- Repeat ability (*Speech intelligibility*) at high input level (75 dB SPL) in quiet and at SNR = 0, 5, 10, 15 dB for both high and low context sentences
  - Repeat (Q)
  - Repeat (N)
- Recall ability in quiet and in noise for both high and low context (*working memory size*)
  - Recall (Q)
  - Recall (N)
    - Adjusted recall (Recall/Repeat) – “compensates” for intelligibility loss
- **Subjective listening effort & tolerable time**
- **Derived scores**
  - **Use of context** (context dependence)
    - 1 – (Low context /high context) - higher number, more dependent on context
  - **Resistance to noise** interference (*Noise resistance, N/Q*)
    - N/Q – higher number, more resistance to noise
WHAT HAVE WE DONE ON THE RRT SO FAR?

- Tested on normal hearing subjects (40-60 yrs, N = 17)
  - Established list equivalence on test materials
  - Established normative performance
  - Determined test-retest reliability
- Tested on hearing impaired subjects (50-70 yrs, N =17)
  - Measured performance using only one topic
  - Aided
- Measured Reading Span Test, MoCA, HINT on all subjects
COMPARISON BETWEEN NORMAL AND HI LISTENERS – REPEAT AND RECALL SCORES
COMPARISON BETWEEN NORMAL AND HI LISTENERS – ADJUSTED RECALL

NORMAL

HEARING IMPAIRED

Adjusted Recall (Rec/Rep)

-5 dB  0 dB  +5 dB  +10 dB  +15 dB  Quiet

SNR

-5 dB  0 dB  +5 dB  +10 dB  +15 dB  Quiet

SNR

High • Low
COMPARISON BETWEEN NORMAL AND HIGHLIGHT LISTENERS – EFFORT AND TOLERABLE TIME

NORMAL

HEARING IMPAIRED

SNR

Effort (1-10)

Tolerable Time (mins)

-5 dB 0 dB +5 dB +10 dB +15 dB Quiet

0 2.5 5.0 7.5 10.0

0 50 100 150

High · Low

High · Low

PRELIMINARY
The anticipation is killing me!
RECALL SCORE IS CORRELATED WITH RST AND MoCA
WHAT DOES GOOD RECALL MEAN? 

RRT SCORES

![Bar charts showing recall in noise (% correct) for different contexts and signal-to-noise ratios (SNR)]

- **Context:** Repeat in Noise (% Correct)
- **0/5/10 dB SNR Quiet:**
  - Good Recall
  - Poor Recall

![Bar charts showing recall in noise (% correct) for different contexts and signal-to-noise ratios (SNR)]

- **Context:** Recall in Noise (% Correct)
- **0/5/10 dB SNR Quiet:**
  - Good Recall
  - Poor Recall

![Bar charts showing effort in noise (Sc. 1-10) for different contexts and signal-to-noise ratios (SNR)]

- **Context:** Effort in Noise (Sc. 1-10)
- **0/5/10 dB SNR Quiet:**
  - Good Recall
  - Poor Recall

![Bar charts showing tolerable time in noise (mins) for different contexts and signal-to-noise ratios (SNR)]

- **Context:** Tolerable Time in Noise (mins)
- **0/5/10 dB SNR Quiet:**
  - Good Recall
  - Poor Recall
HOW DO I **USE** THE RESULTS WITH MY PATIENTS?
DEVELOPING A RRT PATIENT PROFILE (Z-SCORE)

Z-Plot: Repeat Performance (N)

- Context Dependence (Quiet)
- Noise Resist. (High Cnxt)
- Low Context (Noise)
- Context Dependence (Noise)

Z-Plot: Repeat Performance (hi W/NORM)

- Context Dependence (Quiet)
- Noise Resist. (High Cnxt)
- Low Context (Noise)
- Context Dependence (Noise)

Z-Plot: Performance (HEARING IMPAIRED)

- Context Dependence (Quiet)
- Noise Resist. (High Cnxt)
- Low Context (Noise)
- Context Dependence (Noise)
RRT PROFILE – NORMAL AND HEARING IMPAIRED LISTENERS (Z-SCORES)

- **Z-Plot: Repeat Performance**
  - Context Dependence (Quiet)
  - Poorest performance
  - More dependent on context
  - Poorer than normal, esp in noise

- **Z-Plot: Adjusted Recall Performance**
  - Context Dependence (Quiet)
  - Similar to normal in recall

- **Z-Plot: Listening Effort**
  - Context Dependence (Quiet)
  - Upper range of normal effort

**Legends**
- Noise Resist. (High Cnxt)
- Noise Resist. (Low Cnxt)
- High Context (Quiet)
- Low Context (Quiet)
- High Context (Noise)
- Low Context (Noise)

- 2.4
- 2.1
- 1.4
- 1.2
- 0.7
- 0.6
- 0.2
SUBJECT: MO – A “YOUNG” YOUNG

- 36 yrs
- 30 MOCA | 75 RST
- REPEAT poorer than normal, especially low context
- RECALL similar to normal, poorer in low context noise
- EFFORT similar as normal
- Poorer NOISE RESISTANCE than normal
- CONTEXT DEPENDENCE within normal range, except noise
SUBJECT: MS2 – A YOUNG “OLD”

- 80 yrs – looks young, active
- 28 MOCA | 74 RST
- REPEAT much poorer than normal, esp in noise
- RECALL better than normal
- EFFORT higher but within normal range
- Poorer NOISE RESISTANCE for repeat than normal
- CONTEXT DEPENDENCE similar to normal
POTENTIAL CLINICAL UTILITIES FOR RRT

- Results are preliminary - Usefulness has not been determined on a large scale
- Four measures rolled into one test
  - Speech understanding potential
  - Working memory capacity
  - Use of context (in quiet and in noise)
  - Subjective listening effort in realistic, loud situations
- Maintains motivation
  - Efficiency (8 minutes for quiet and 1 SNR to 25 minutes for quiet and 4 SNR)
  - Without the appearance of MCI/dementia testing or difficulty with RST
- Characterization (or profiling) of patients
  - Comparison with normal (or hearing impaired norms) of same age
  - Pinpoint areas of strength & weakness
  - Direct focus for rehabilitation
  - Grouping patients for research
- Comparison between aided and unaided listening
- Demonstrate benefits of hearing aid feature?
If you are interested in gathering more normative data for us or making the test in your language, please let me (fkuk@widex.com) or my colleagues know.
CONCLUSIONS

• Speech understanding, albeit important, cannot be the only criterion for measuring hearing aid benefits
  • Listening effort (various measures, including TNT) may offer complementary view

• Measuring the cognitive ability of the patients is important
  • Explains clinical findings
  • Selects optimal amplification
  • Guides rehabilitation
  • RRT may offer efficient solution

• Ultimate goal: Listening (and speech understanding) should be effortless – we need to make it so and be able to verify that
THANK YOU FOR YOUR LISTENING EFFORT
AND MY WONDERFUL STAFF AT ORCA-USA