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Electrophysiology and Perception of Speech in Noise: Research Update from National Center for Rehabilitative Auditory Research (NCRAR)

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Rehabilitation Research & Development
National Centers of Excellence

- Limb Loss & Prosthetics (Seattle, WA)
- Functional Electrical Stimulation (Cleveland, OH)
- Wheelchair Technology (Pittsburgh, PA)
- Innovactive Visual Rehabilitation (Boston, MA)
- Restorative & Regenerative Medicine (Providence, RI)
- Spinal Cord Injury & MS (West Haven, CT)
- Spinal Cord Injury (Bronx, NY)
- Exercise & Robotics (Baltimore, MD)
- Auditory Rehabilitation (Portland, OR)
- Bone & Joint Rehabilitation (Palo Alto, CA)
- Platform Technology (Cleveland, OH)
- Aging & Vision Loss (Decatur, GA)
- Brain Rehabilitation (Gainesville, FL)
- Spinal Cord Injury (Miami, FL)
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**Prevention of Auditory Dysfunction**
- Ototoxicity
- Telehealth
- Tinnitus
- Aging and the auditory system
- Auditory Rehabilitation
- Ear-Brain system
- Hearing aids
- Hearing conservation
- Traumatic Brain Injury (TBI)
The Problem: Poor Speech Perception in Noise

Cocktail Party Effect

- automobile
- restaurants
- meetings
- concerts
- telephone

Signal-to-noise ratio (SNR):

| Signal | +5 | 0 | -5 |

Billings-AudiologyOnline (10-29-2014)
The Problem: Poor Speech Perception in Noise

- Common problem for older individuals and individuals with hearing impairment
- Most frequent complaint among hearing aid users
- Difficult situation for many Veterans (e.g., traumatic brain injury, multiple sclerosis, etc.)

Our approach: Combine behavior with brain measures to improve understanding of perception-in-noise difficulties

Topics for Today

1. Intro to physiological measures & signals in noise (absolute signal level vs. of signal-to-noise ratio)
2. Implications for aided evoked potentials
3. Relationship between brain & behavior
4. Noise type: energetic & informational masking
How do we measure the central auditory system in humans?
- EEG / MEG / PET / fMRI

**Comparison of Brain Measures**

<table>
<thead>
<tr>
<th></th>
<th>Single/Multiple Unit Methods</th>
<th>Hemodynamic Methods</th>
<th>Electromagnetic Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasiveness</td>
<td>Very invasive</td>
<td>Somewhat invasive (PET)</td>
<td>Non-invasive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-invasive (fMRI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-invasive (DTI)</td>
<td></td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>Excellent</td>
<td>Good</td>
<td>Poor (EEG)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mediocre (MEG)</td>
</tr>
<tr>
<td>Temporal Resolution</td>
<td>Excellent</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Cost</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Inexpensive (EEG)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expensive (MEG)</td>
</tr>
</tbody>
</table>
What are Auditory Evoked Potentials (AEPs)?
What are Auditory Evoked Potentials (AEPs)?

- type of EEG involving a stimulus
- voltage changes over time in response to an auditory stimulus
- electrical signals generated by neurons
- sum of synchronous neural activity
- recorded at the scalp

Auditory Evoked Potentials

Latency: neural conduction time
Amplitude: voltage change
**P1-N1-P2**
(a.k.a., vertex potential, obligatory response, slow cortical response, CAEP, ACC, etc)

Sensitive to acoustics of a stimulus

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**Perception In Noise Factors**

**Good vs Poor Performers**

- **Subject factors**: hearing status, age, medical history, innate ability, cognitive processing, neural plasticity & learning, etc.

- **Stimulus factors**: signal level, SNR, signal type, noise type, spatial separation, multisensory, etc.
Auditory Evoked Potentials

Increases in stimulus intensity

- amplitude \( \uparrow \)
- latency \( \downarrow \)

Effect of SNR & tone level

Question:
What is the effect of tone level and SNR on P1-N1-P2 complex?
Effect of SNR & tone level

Question:
What is the effect of tone level and SNR on P1-N1-P2 complex?

Hypothesis:
Amplitude and latency will change with SNR rather than with absolute tone level

Subjects: 15 normal hearing
Stimuli: tones in noise
- 1k Hz tone: 750 ms duration; 7 ms rise/fall
- Noise: shaped white noise
12 Conditions (no hearing aid)
- 2 tones levels: 60 & 75 dB SPL
- 6 SNRs: Quiet, 20, 10, 0, -5, -10 dB

AEPs demonstrate sensitivity to SNR rather than absolute signal level

(Billings et al., Hear Res 254(1-2):15, 2009)
Caveat #1: Noise can enhance N1 amplitude

- Effects of noise:
  - increases in latency
  - decrease in amplitude

Billings-AudiologyOnline (10-29-2014)
Caveat #1: Noise can enhance N1 amplitude

- Binaural presentation, fast presentation rates (1/sec), inclusion of low frequency neural activity (1-3 Hz)

(Papesh et al., Clin Neurophys, in press)

Caveat #2: Loudness modifies SNR effect

- An effect of loudness when it is varied but SNR is held constant (3-dB SNR)

(Sharma et al., Neuroreport, 2014)

Topics for Today

(1) Intro to physiological measures & signals in noise (absolute signal level vs. of signal-to-noise ratio)
(2) Implications for aided evoked potentials
(3) Relationship between brain & behavior
(4) Noise type: energetic & informational masking
Aided AEPs: recording AEPs while an individual is wearing a hearing aid

Possible uses of AIDED P1-N1-P2

- Measure acclimatization and neural change over time after hearing aid fitting
- Estimate an aided threshold
- Compare neural responses of successful and unsuccessful hearing aid users
- Measure neural changes that occur with auditory training
**Hypothetical Example**

- **tone=50dB**
  - **noise=30dB**
- **10dB gain**
  - **tone=60dB**
  - **noise=40dB**
- **25dB gain**
  - **tone=75dB**
  - **noise=55dB**

**Effect of HA Gain**

**Question:** What is the effect of hearing aid gain on P1-N1-P2 complex?

**Hypothesis:** Amplitude and latency will change depending on SNR levels.
More robust responses in unaided condition compared to the aided condition as a result of larger SNRs.

(Billings et al., *Int J Audiol*, 2011)

More to Consider:
- Circuit noise, freq response, compression (Jenstad et al., *Int J Otolaryng*, 2012)
- Audibility of noise in hearing impaired

(Billings-AudiologyOnline (10-29-2014))
Two Approaches: detection vs. discrimination

Detection-like

- n=7
- Severe to profound SNHL
- 80 dB SPL

Discrimination-like

- n=4
- Moderate SNHL
- 85 dB SPL

Physiological Detection Approach

A. McNeill et al. (2009)

Physiological Discrimination Approach

E. Billings et al. (2007)

H. Billings et al. (2011)
Caveat #3: Is the aided physiological discrimination approach always problematic?

- Physiological discrimination works in some cases, especially in cases involving timing (strength of EEG)

- However, many unaided-to-aided or aided-to-aided clinical comparisons are not timing related (e.g., gain, frequency response)

- Key issue: we still do not know what hearing aid modifications can be demonstrated above threshold (i.e., discrimination approach)

(Billings et al., Int J Otolaryng, 2012)

(Tremblay et al., Ear Hear, 2006)
Caveat #4: What does a physiological detection threshold tell us?

• The sound is reaching the cortex
• The behavioral threshold is usually within 10 dB (but as much as 20 dB different)
• Absent response is non-diagnostic (tells us nothing)

How useful is a physiological detection threshold?

• Similar to a behavioral aided threshold; although, not as accurate
• Provides only limited information about the adequacy of HA fit

Clinical Significance:

1. Ready to use aided AEPs clinically?  - For detection: Yes
   - For discrimination: No

2. Better understanding needed of interactions between device, auditory system, and stimuli
1. Ready to use aided AEPs clinically?
   - For detection: Yes
   - For discrimination: No

2. Better understanding needed of interactions between device, auditory system, and stimuli

3. Two stimulus factors that we know have an effect:
   a) SNR: background noise must be minimized
   b) onset modifications
   c) others?

Clinical Significance:

<table>
<thead>
<tr>
<th>Patient</th>
<th>Device</th>
<th>Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>hearing loss configuration</td>
<td>compression settings</td>
<td>spectral characteristics</td>
</tr>
<tr>
<td>hearing loss degree</td>
<td>frequency response</td>
<td>temporal characteristics</td>
</tr>
</tbody>
</table>

Topics for Today

(1) Intro to objective measures & signals-in-noise
   • Effects of absolute signal level
   • Effects of signal-to-noise ratio
(2) Implications for aided evoked potentials
(3) Relationship between brain & behavior
(4) Noise type: energetic & informational masking
Perception In Noise Factors

Good vs Poor Performers

- Subject factors: hearing status, age, medical history, innate ability, cognitive processing, neural plasticity & learning, etc.

- Stimulus factors: signal level, SNR, signal type, noise type, spatial separation, multisensory, etc.

Relationship between brain & behavior

- Signals:
  - 4 signal levels = 50, 60, 70, and 80 dB SPL
  - Electrophysiology = syllable /ba/; 1000 Hz tone
  - Behavior = IEEE sentences; words in noise; Acceptable Noise Level
Relationship between brain & behavior

- **Signals:**
  - 4 signal levels = 50, 60, 70, and 80 dB SPL
  - Electrophysiology = syllable /ba/; 1000 Hz tone
  - Behavior = IEEE sentences; words in noise; Acceptable Noise Level

- **Noise:**
  - continuous speech-spectrum noise
  - SNRs ranging from -10 to 35 dB

<table>
<thead>
<tr>
<th>Signal Level (dB SPL)</th>
<th>-10</th>
<th>-5</th>
<th>0</th>
<th>+5</th>
<th>+15</th>
<th>+25</th>
<th>+35</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>60</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh/CAEP</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>70</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh/CAEP</td>
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<td>80</td>
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<td>Beh/CAEP</td>
<td>Beh</td>
<td>Beh/CAEP</td>
<td>Beh/CAEP</td>
<td>Beh/CAEP</td>
<td>Beh/CAEP</td>
</tr>
</tbody>
</table>

B = Behavioral testing; EP = Evoked Potential; — = Did not test

Electrophysiology

Latency: neural conduction time
Amplitude: voltage change
Relationship between brain & behavior

**Electrophysiology**

![Graph showing signal-to-noise ratio (SNR) vs. latency (ms) for different dB levels.]

**Relationship between brain & behavior**

**Young Normal-Hearing**

**Behavior**

- Accuracy (% Correct)

**Electrophysiology**

- N1 Latency
- P2 Latency

*Figure 5:* Behavior (left) and electrophysiology (right) for the young normal-hearing group.

(Billings et al., *JARO*, 2013)
**Correlations**

- Behavior vs. Electrophysiology
  - SNR50 vs. Peak value
- N1 stood out as best correlate, especially amplitude

**Predictions**

- Partial least squares regression used to predict behavior from electrophysiology measures
- Leave-one-out-cross-validation approach used to minimize bias associated with prediction based on same sample
- Using electrophysiology, able to predict behavioral SNR50 to within 1 dB in young normal-hearing individuals

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**Relationship between brain & behavior**

- Young normal-hearing (YNH; n=15)
- Old normal-hearing (ONH; n=15)
- Old hearing-impaired (OHI; n=15)

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**Billings-AudiologyOnline (10-29-2014)**

(Billings et al., *JARO*, 2013)

(Billings et al., *submitted*)
Relationship between brain & behavior

\[ \text{Behavior} \]

Group Performance

- Difference between YNH and ONH (i.e. age effect) 
  \[ \approx 2 \text{ dB} \]

- Difference between ONH and OHI (hearing loss effect) 
  \[ \approx 10 \text{ dB} \]

(Billings et al., submitted)

Electrophysiology
Using brain measures to predict behavior (SNR50)

**Prediction Accuracy With YNH Prediction Model:**
- predictions of YNH SNR50 within 1 dB
- predictions of ONH SNR50 within about 2 dB
- predictions of OHI SNR50 within 16 dB

Using brain measures to predict behavior (SNR50)

**Prediction Accuracy With OHI Prediction Model:**
- Predictions of OHI SNR50 within 6 dB
- Needs improvement to be clinically meaningful
Topics for Today

(1) Intro to physiological measures & signals in noise
   (absolute signal level vs. of signal-to-noise ratio)
(2) Implications for aided evoked potentials
(3) Relationship between brain & behavior
(4) Noise type: energetic & informational masking

Perception In Noise Factors

- **Subject factors**: hearing status, age, medical history, innate ability, cognitive processing, neural plasticity & learning, etc.
- **Stimulus factors**: signal level, SNR, signal type, noise type, spatial separation, multisensory, etc.
Effect of Noise Type

- Performance is affected by noise type:
  - Release from masking (dip listening)
  - Energetic vs. informational masking

Energetic masking refers to a target and masker that overlap in time and frequency resulting in portions of the target that are inaudible; interference within in cochlea (Kidd et al., 2008).

Informational masking occurs when the target and masker are both audible, but the listener has a reduced ability to identify the target; cannot be explained solely by interactions in periphery; uncertainty and similarity (Brungart et al. 2001; Durlach et al, 2003).

Effect of Noise Type

- Subjects: 9 normal hearing
- AEPs and behavior
- Oddball Paradigm:
  1) tone contrast (standard = 1000 Hz; deviant = 500 Hz)
  2) speech contrast (standard = /ba/; deviant = /da/)

- AEPs:
  - N1-P2 obligatory responses, affected by acoustics of stimulus
  - P3 is attentional, reflects cognition and speech processing abilities

- Behavior:
  - Oddball reaction time to deviant recognition (msec)
  - Oddball discrimination accuracy (percent correct)
  - IEEE Sentences in noise (percent correct)
Effect of Noise Type

4 Noise Conditions (-3 dB SNR)
1) Quiet
2) Continuous speech spectrum noise
3) Interrupted
4) Four-talker babble

Brain Results: N1-P2 Complex

Brain Results: N1-P2 Complex

Latency (ms)

Amplitude (µV)

Interrupted Noise
Gap Trials
Noise Trials

Results: P300 Waveform

Amplitude (µV)

Tone 500Hz

Speech /da/

Quiet
Interrupted
Continuous
Babble


Behavioral Results: Reaction Time

![Graph showing reaction time in milliseconds for quiet, interrupted, continuous, and babble conditions for tone and speech stimuli.]

Bennett et al., *Ear Hear* 32:231-8, 2012

Behavioral Results: % Correct

![Graph showing % correct for quiet, interrupted, continuous, and babble conditions for tone, speech, and sentences.]

Bennett et al., *Ear Hear* 32:231-8, 2012
Brain & Behavior: P3 & Reaction Time

\[ R^2 = 0.6202 \]

- Speech-Babble
- Speech-Continuous
- Speech-Intermittent
- Tone-Babble
- Tone-Continuous
- Tone-Intermittent

Brain & Behavior: P3 & % Correct

\[ R^2 = 0.5608 \]

- Speech-Babble
- Speech-Continuous
- Speech-Intermittent
- Tone-Babble
- Tone-Continuous
- Tone-Intermittent

Conclusions

- Signal-to-noise ratio is a main stimulus factor affecting brain & behavior.
- Informational masking (babble) interfered with brain encoding; limited release from masking with interrupted noise.
- Age and hearing impairment are important subject factors for brain & behavior.
- Brain measures are correlated with behavior and can predict behavior well in some populations.

- From the Lab → Cocktail Party:
  - reduce the SNR (volume &/or distance)
  - use all of your senses (hearing + vision)
  - separate sources in space
  - change the environment
  - hearing assistive devices (hearing aids, FM systems, etc)

How does this impact the clinic?

31 yo male

- Referred to ENT by PCP because of vertigo
- Concussion and temporal bone fracture after fall
- Vertigo, tinnitus, headaches
- Hx of noise exposure; 2 deployments (6 years)
- PTSD, depression, easily distracted, needs repetition
- "Why do I have normal hearing but can’t seem to understand the speech of others?"
- Couldn’t finish testing due to fatigue
- Performed poorly on all subtests

30 yo male

- Referred by polytrauma; being evaluated for mTBI
- Concussion when truck flipped in Iraq
- Tinnitus, Hx of noise exposure
- PTSD, depression, anxiety, cognitive difficulties
- Needed breaks after every test; nausea because of anxiety (trying not to vomit)
- Performed poorly on all subtests
- Was it due to anxiety?
How does this impact the clinic?

**Good vs Poor Performers**

- **Subject factors**: Subject factors: hearing status, age, medical history, innate ability, cognitive processing, neural plasticity & learning, etc.
- **Stimulus factors**: signal level, SNR, signal type, noise type, spatial separation, multisensory, etc.

**Improve diagnosis/assessment and tailor treatment to the needs of the individual**

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**Thank You!**

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http://www.ncrar.research.va.gov/
References


Billings-AudiologyOnline (10-29-2014)