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Assessing Auditory Processing Abilities in Blast-Exposed Veterans

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The opinions expressed do not necessarily reflect the position or policy of the Department of Veterans Affairs or the government of the United States
National Center for Rehabilitative Auditory Research (NCRAR)
VA Portland Health Care System

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

VA RR&D Centers of Excellence

- Limb Loss & Prosthetics (Seattle, WA)
- Wheelchair Technology (Pittsburgh, PA)
- Traumatic Brain Injury (Boston, MA)
- Neurorestoration and Neuroregeneration (Providence, RI)
- Auditory Rehabilitation (Portland, OR)
- Vision Loss (Iowa City, Iowa)
- Advanced Platform Technology (Cleveland, OH)
- Nervous System Restoration (West Haven, CT)
- Functional Electrical Stimulation (Cleveland, OH)
- Vision and Neurocognitive Rehabilitation (Atlanta, GA)
- Brain Rehabilitation (Gainesville, FL)
- Spinal Cord Injury (Bronx, NY)
- Exercise & Robotics (Baltimore, MD)
Learning Objectives

After this course learners will be able to:
• Describe the potential effects of blast exposure on the central auditory system.
• List the behavioral and electrophysiological tests of central auditory processing appropriate for testing patients exposed to high-intensity blasts or other brain traumas.
• Describe the types of central auditory processing deficits found among those with brain trauma.

Organization of Presentation

• Background
  – Hearing Complaints of Veterans with “Normal” Hearing
  – Auditory system physiology and function
  – Potential for injury to the auditory system
• History of Central Auditory Processing and TBI
• Recent Developments
• Future Directions
Blast Exposure and Traumatic Brain Injury (TBI)

One of the most common effects of blast exposure is mild TBI, also known as concussion.

What is mild TBI?

- Traumatic brain injury (TBI) is a common condition, especially among military members.
- Twelve to 23 percent of service members returning from Operations Enduring Freedom, Iraqi Freedom, and New Dawn (OEF/OIF/OND) experienced a TBI while deployed.
Severity of Brain Injury

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal structural brain imaging</td>
<td>Normal or abnormal structural brain imaging</td>
<td></td>
</tr>
<tr>
<td>Loss of Consciousness (LOC) = 0 – 30 minutes</td>
<td>LOC &gt; 30 minutes and &lt; 24 hours</td>
<td>LOC &gt; 24 hours</td>
</tr>
<tr>
<td>Alteration of consciousness (AOC) = a moment up to 24 hours</td>
<td></td>
<td>AOC &gt; 24 hours</td>
</tr>
<tr>
<td>Posttraumatic amnesia (PTA) = 0 - 1 day</td>
<td>PTA &gt; 1 and &lt; 7 days</td>
<td>PTA &gt; 7 days</td>
</tr>
<tr>
<td>Glasgow Coma Scale (GCS) = 13 – 15</td>
<td>GCS = 9–12</td>
<td>GCS = 3–8</td>
</tr>
</tbody>
</table>

Common Symptoms of mild TBI

- Dizziness
- Loss of Balance
- Poor coordination
- Headaches
- Nausea
- Poor concentration
- Forgetfulness
- Difficulty making decisions
- Slowed thinking
- Fatigue
- Insomnia
- Body/extremity numbness
- Light sensitivity
- Hearing difficulty
- Noise sensitivity
- Visual disturbance
- Altered taste or smell
- Appetite change
- Feeling anxious
- Feeling depressed
- Easily irritated
- Poor frustration tolerance
Not All Blast Exposed Veterans Have a Diagnosis of TBI

- The list of symptoms is highly overlapping with the symptoms of many other disorders that can follow blast exposure.
- Accurate diagnosis of mild TBI is difficult due to the lack of clear indicators in the brain imaging results and the lack of prolonged loss or alterations of consciousness.
- Recent animal studies have shown that the blast wave can impact the brain without producing immediate symptoms.
- It is possible that brain injury in humans can also occur without producing the clinical symptoms needed to produce a diagnosis of mild TBI.

Common Communication Complaints of Blast Exposed Veterans

- “I can’t follow a conversation in a crowded room.”
- “Sometimes I get frustrated when people talk too fast or mumble.”
- “My hearing problem impacts both my work and family relationships.”
Central Auditory Dysfunction in VA Clinics

1. Informal email survey of 220 VA audiologists conducted by Saunders, Chisolm, Abrams, and Meyers in 2009:
   - how often do you encounter OEF/OIF veterans complaining of hearing difficulties who have normal or almost normal thresholds?
   - what rehabilitation do you provide for these individuals?

2. 89 audiologists responded, representing about 82 different sites.

“How often do you encounter OEF/OIF Veterans complaining of hearing difficulties who have normal or almost normal peripheral hearing?”

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>Never</th>
<th>Less than one per month</th>
<th>1-3 per month</th>
<th>4 or more per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of responses</td>
<td>2%</td>
<td>6%</td>
<td>53%</td>
<td>39%</td>
</tr>
</tbody>
</table>

VETERANS HEALTH ADMINISTRATION
Central Auditory Dysfunction in VA Clinics

“What rehabilitation do you provide?”
(over half gave multiple responses, so the numbers don’t add up to 100%)

<table>
<thead>
<tr>
<th></th>
<th>Hearing Aids</th>
<th>Remote Microphone</th>
<th>Auditory Training</th>
<th>Other (OAEs, ABRs, referral, etc.)</th>
<th>Unsure of What To Do</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Responses</td>
<td>26</td>
<td>29</td>
<td>23</td>
<td>44</td>
<td>27</td>
</tr>
<tr>
<td>% of responses</td>
<td>29%</td>
<td>33%</td>
<td>26%</td>
<td>49%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Relevance Outside of VA

Approximately 50% of returning Veterans seek healthcare outside the VA system

More than half of returning Iran and Afghanistan Veterans report multiple blast exposures
Organization of Presentation

• Background
  – Hearing Complaints of Veterans with “Normal” Hearing
  – Auditory system physiology and function
  – Potential for injury to the auditory system
• History of Central Auditory Processing and TBI
• Recent Developments
• Future Directions
Functions of the Central Auditory System

**Auditory Cortex:**
Feature-specific processing of auditory information

**Corpus Callosum:**
Transfer information between left and right hemispheres

**Parietal Cortex:**
Spatial information

**Frontal Cortex:**
Control of attention, task-dependent activity, and plasticity of the system over time.

Central Damage due to Blast Exposure: Model Predictions

- injury to axons (stretching and shearing of axons)
- bruising of the brain surface (contusion)
- internal bleeding (subdural hemorrhage) from ruptured blood vessels

Potential Damage to the Auditory System from Blast Exposure

• Peripheral
  – Pinna
  – Tympanic Membrane
  – Ossicular Chain
  – Cochlea
• Central
  – Brainstem
  – Corpus Callosum
  – Temporal Lobe
  – Frontal Lobe

Damage to Auditory Brain Areas:
I. Primary Mechanism:
Blast Pressure Wave from Explosion

– Stretching or shearing of thalamus and corpus callosum connections
– resulting in disconnection of inputs or cell death.

Contusions: blue
Diffuse axonal injury: pink
Taber et al., 2006
Potential Impacts of Damage to Brainstem and Thalamus on Auditory Processing

- Reduced sensitivity to:
  - Binaural information
  - Temporal Modulation
  - Spectral and Pitch information

- Impairments in:
  - Formation of auditory representations
  - Complex computations involving auditory information
  - Creation of novel relationships and associations through cortical plasticity

Damage to Auditory Brain Areas:
II. Secondary and Tertiary Mechanisms: Blunt Head Trauma, Penetrations

- Contusions to temporal and frontal lobes
- Hemorrhage damage to frontal and parietal lobes

Contusions: blue  
Hemorrhage: purple  
Taber et al., 2006
Potential Impacts of Cortical Damage on Auditory Processing

• Reduced speech intelligibility
• Impaired spatial perception
• Decreased accuracy on specific tasks performed by precisely tuned components of the ear-brain system
• Decreased attentional focus
• Decreased performance on tasks involving task-dependent selection and segregation of competing information

Organization of Presentation

• Background
  – Hearing Complaints of Veterans with “Normal” Hearing
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  – Potential for injury to the auditory system
• History of Central Auditory Processing and TBI
• Recent Developments
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## Auditory Processing and Brain Injury

- Prior to the current conflicts in Iraq and Afghanistan, most of the work had involved strokes, tumors, or penetrating head wounds.
- This allowed clear associations among site of lesion and type of dysfunction.
- Tests were developed that were resistant to peripheral loss.

## Vietnam Head Injury Study (1967-present)

- Four phases over four decades.
- Focuses primarily on penetrating wounds.
- Phase Two (1978-1987) tested for deficits in auditory processing abilities.
- Results confirmed and extended the evidence that cortical and brainstem lesions could be diagnosed using auditory and speech tests.
Sensitivity and Specificity of Behavioral Tests for Central Auditory Lesions

<table>
<thead>
<tr>
<th>Test</th>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influence of hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotic Digits Test (DDT)</td>
<td>Cortex</td>
<td>80%</td>
<td>80%</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Pattern Test (FPT)</td>
<td>Cortex</td>
<td>85% (cerebral)</td>
<td>88%</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td>45% (brainstem)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gaps-in-Noise (GIN)</td>
<td>Cortex</td>
<td>67%</td>
<td>85%</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masking Level Difference (MLD)</td>
<td>Brainstem</td>
<td>89%</td>
<td>92%</td>
<td>May be compensated</td>
</tr>
</tbody>
</table>

Musiek (1983); Musiek et al. (1991); Bamiou et al. (2006); Musiek and Pinhero (1987); Humes et al. (1996); Musiek et al. (2005); Olsen et al. (1976); Jerger et al. (1984).

Electrophysiological Measures of Auditory Processing

<table>
<thead>
<tr>
<th>Test</th>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influence of hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABR (Wave V latency)</td>
<td>Brainstem</td>
<td>80%</td>
<td>75%</td>
<td>Resistant/Compensable</td>
</tr>
<tr>
<td>LLR (P300)</td>
<td>Cortex</td>
<td>80%</td>
<td>70%</td>
<td>May be compensated</td>
</tr>
</tbody>
</table>
P300 in TBI patients


fMRI study of auditory oddball task

Witt et al. (2010) Brain Imaging and Behavior. 4:232-247
Organization of Presentation

- Background
  - Hearing Complaints of Veterans with “Normal” Hearing
  - Auditory system physiology and function
  - Potential for injury to the auditory system
- History
  - Central Auditory Processing and TBI before 2008
- Recent Developments
- Future Directions

Performance on tests of central auditory processing by individuals exposed to high-intensity blasts

JRRD, 49 (7) : 1005 — 1024

VA RR&D Merit Award B5067R

- Blast exposed service members tested at Walter Reed within one year of exposure
- Control group with same age and pure tone thresholds as blast group
Participants

Blast Exposed (n = 36)
- Tested at Walter Reed Army Medical Center
- Recently exposed to a blast
- 19 with mild TBI
- 17 without TBI diagnosis
- OEF/OIF soldiers
- Treated for other blast related injuries
- No greater than mild hearing loss

Control Subjects (n = 29)
- Tested at NCRAR
- Non-blast exposed
- Age matched (+/- 5 years)
- Hearing matched (+/- 10dB at octave freq.’s)

---

<table>
<thead>
<tr>
<th>Mean Values</th>
<th>Blast</th>
<th>Control</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>32.8</td>
<td>32.1</td>
<td>n.s.</td>
</tr>
<tr>
<td>Pure Tone Average (dB HL)</td>
<td>13.2</td>
<td>7.0</td>
<td>p &lt; .01</td>
</tr>
</tbody>
</table>
CAPD & Blast Exposure Test Protocol

Speech in Noise and Competing Speech
- QuickSIN
- Dichotic Digits (DD)
- Staggered Spondaic Words Test (SSW)

Localization and Spatial Processing
- Binaural Masking Level Differences (MLD)

Temporal Processing
- Gaps In Noise Test (GIN)
- Frequency Pattern Sequences Test (FP)

Electrophysiology
- ABR
- P300

![Graph showing percentage of subjects scoring outside the normal range for different tests: Blast (n=36) vs Control (n=29)]
How Many Abnormal Results?

- Clinical practice guidelines generally suggest that abnormal performance on **two** tests of central auditory function is necessary for a diagnosis of auditory processing disorder.
Electrophysiology: Auditory Brainstem Responses (ABR)

No statistical differences between the groups, which is consistent with the normal or near-normal audiograms of all participants.

Electrophysiology: Long Latency Responses

Cortical potentials (N1) did not differ, but cognitive potentials (P2/P300) were reduced and delayed in blast group.

Consistent with intact peripheral coding (cochlea through auditory cortex) and impaired central processing.
2014 Institute of Medicine Report

Gulf War and Health, Volume 9: Long-Term Effects of Blast Exposures

IOM 2014: Long-Term Effects of Blast Exposures

“It is possible that blast causes dysfunction in dimensions of auditory function beyond declines in hearing acuity, which may go undetected or unnoticed in the immediate period after exposure, and there is no consensus on whether this dysfunction has long-term consequences and how long changes in auditory processing abilities may persist after hearing thresholds return to pre-blast values.”
Central Auditory Processing Deficits Associated with Blast Exposure
VA RR&D Merit Award C7755I

Frederick Gallun, PhD (Principal Investigator)
Marjorie Leek, PhD (co-Principal Investigator)
Robert Folmer, PhD (co-investigator)
M. Samantha Lewis, PhD (co-investigator)
Michele Hutter, MS (co-Investigator)
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Heather Belding, BS (Research Assistant)
*Serena Dann, AuD (Research Audiologist)
*Sean Kampel, AuD (Research Audiologist)
*Daniel McDermott, MA (Research Audiologist)
*Tina Penman, AuD (Research Audiologist)
*not pictured

Participants

- **BLAST GROUP:** 38 blast-exposed Veterans
  - Mean age: **36.9 years** (sd 10.6)
  - Average time since blast exposure: **7.8 years**
  - Average number of blasts reported: **6.9 blasts**

- **CONTROL GROUP:** 29 age- and hearing-matched participants with no history of brain injury.
  - Mean age: **39.5 years** (sd 13.2)
Self-Report: Hearing Handicap Inventory – Adult

- 25-item questionnaire addressing the impact of hearing-related problems on emotional and social functioning

63% of blast-exposed report moderate or severe hearing handicap
Percentage Abnormal

Tests of Central Auditory Function

Behavioral results adapted from Gallun et al. (under review), JRRD

GIN vs FPT

Frequency Pattern Test (Right Ear, Number of Errors)
SSW vs DDT

SSW vs FPT

CONTINUED™
Electrophysiology: Participants

<table>
<thead>
<tr>
<th></th>
<th>Blast-Exposed (n=25)</th>
<th>Control (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) – Mean ± s.d.</td>
<td>38.9 ± 11.2</td>
<td>38.2 ± 12.3</td>
</tr>
<tr>
<td>Total number of exposures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>8 subjects</td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td>5 subjects</td>
<td></td>
</tr>
<tr>
<td>6-10</td>
<td>10 subjects</td>
<td>0</td>
</tr>
<tr>
<td>11-20</td>
<td>1 subject</td>
<td></td>
</tr>
<tr>
<td>&gt;20</td>
<td>1 subject</td>
<td></td>
</tr>
<tr>
<td>Mean (± s.d.) number of blast exposures per subject</td>
<td>6.1 ± 7.7</td>
<td>0</td>
</tr>
<tr>
<td>Years since last blast exposure – Mean ± s.d.</td>
<td>8.1 ± 1.8</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Electrophysiological results adapted from Folmer et al. (under review), J Neurotrauma
Auditory Brainstem Response

- All members of both groups exhibited clinically normal ABRs in response to click stimuli.
- However, ABR components shown in bold below differed significantly between groups. Differences are likely attributable to the differences in thresholds.
- These results are consistent with normal auditory processing at the cochlea and brainstem.

<table>
<thead>
<tr>
<th></th>
<th>Wave I</th>
<th>Wave III</th>
<th>Wave V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>latency</td>
<td>amplitude</td>
<td>latency</td>
</tr>
<tr>
<td><strong>RIGHT EAR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast</td>
<td>1.77</td>
<td>0.15</td>
<td>4.01</td>
</tr>
<tr>
<td>Control</td>
<td>1.68</td>
<td>0.23</td>
<td>3.87</td>
</tr>
<tr>
<td><strong>LEFT EAR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast</td>
<td>1.76</td>
<td>0.21</td>
<td>3.88</td>
</tr>
<tr>
<td>Control</td>
<td>1.68</td>
<td>0.25</td>
<td>3.87</td>
</tr>
<tr>
<td><strong>BINAURAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blast</td>
<td><strong>1.78</strong></td>
<td><strong>0.16</strong></td>
<td><strong>3.94</strong></td>
</tr>
<tr>
<td>Control</td>
<td>1.70</td>
<td>0.23</td>
<td>3.83</td>
</tr>
</tbody>
</table>

VETERANS HEALTH ADMINISTRATION
Long latency responses to Oddball Paradigm

- “Oddball paradigm”
  - Common stimuli (500Hz) 80%
  - Rare stimuli (1000Hz) 20%
- Subjects count rare tones silently and ignore common tones
- Rare tones generate a late (~300 ms post-onset) positivity or “P300”

LLR to Frequent Tone (500 Hz)

![Graph showing N100 and P200 waves in response to frequent tones in Blast and Control groups.](image)
LLR to Rare Tone (1000 Hz)

- Blast (n = 25)
- Control (n = 25)

LLR to Dichotic Digits

- Pairs of digits presented to left and right ears
- Target is the digit “4”
LLR to Non-Target Digits: Right Ear

- Blast (n = 25)
- Control (n = 25)

LLR to Non-Target Digits: Left Ear

- Blast (n = 25)
- Control (n = 25)
LLR to Target Digit: Right Ear

- Blast (n = 25)
- Control (n = 25)

LLR to Target Digit: Left Ear

- Blast (n = 25)
- Control (n = 25)
LLR to Gaps in Noise

- Sequences of noise bursts with silent gaps
- Gaps of 2, 4, 6, 8, or 20 ms

LLR to 20 ms Gap

Graph showing N100 and P300 responses to noise onset and 20 msec gaps.
LLR to 8 ms Gap

P300 response to noise onset

LLR to 4 ms Gap

P300 response to noise onset

No discernable response to 4 msec gaps
Conclusions

• Both behavioral and electrophysiological results suggest that blast exposure can have long-lasting impacts on auditory processing
• Auditory processing abilities of blast-exposed Veterans are not uniformly degraded; specific deficits can be identified for individual listeners

Organization of Presentation

• Background
  – Hearing Complaints of Veterans with “Normal” Hearing
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  – Potential for injury to the auditory system
• History
• Recent Developments
• Future Directions
**Structural and Functional Imaging**

- The behavioral difficulties and electrophysiological abnormalities observed need to be tied to specific brain processes.
- New imaging approaches should be used in combination with behavioral and electrophysiological methods.

**Individualized Medicine**

- Blast exposure and traumatic brain injury leads to diverse behavioral effects.
- A battery of tests is needed to identify the difficulties each patient is having.
- Team approach to diagnosis and treatment.
- Only by distinguishing which difficulties exist can targeted rehabilitation be applied.
Rehabilitation Approaches
Need Evidence

- Clinical experience suggests that hearing aids with low gain settings and remote microphones can help
- Brain training has potential but requires better methods of ensuring compliance
- Evidence is needed to guide clinical practice

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Thanks to all of our participants!

Please feel free to contact me:
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