Auditory Processing Dysfunction Related to Traumatic Brain Injury in the Veteran Population

Frederick J. Gallun, PhD
Stephen A. Fausti, PhD
Marjorie R. Leek, PhD
National Center for Rehabilitative Auditory Research (NCRAR)

VA Medical Center, Portland, Oregon
Objectives

- Describe the auditory brain structures that could be damaged in Traumatic Brain Injury.

- Describe the relationship between damage to auditory brain structures and various types of auditory processing dysfunction.

- Discuss the types of behavioral and electrophysiological testing that might be useful in determining the rehabilitation needs of a patient with known or suspected injury to auditory brain areas.

- Discuss the challenges associated with using tests of auditory processing with the veteran population.
More Than Noise Exposure: Blast Injury

- 11% - 28% of 1.4 million troops who have served in OEF/OIF may have mild TBI from blast exposure.
- 30% of casualties treated at Walter Reed Army Medical Center have mild, moderate or severe TBI.

USA Today (3/8/07)
More Than Noise Exposure: Blast Injury

- Improvements in armor and military medicine have increased the chances of survival, but the result is a higher number of survivors with devastating injuries.

- One of the structures most commonly injured in an explosion is the peripheral auditory system. Is the central auditory system similarly at risk?
1. Mechanisms of Blast Injury
Mechanisms of Blast Injury

- **Primary:**
  - impact of blast wave

- **Secondary:**
  - shrapnel, debris

- **Tertiary:**
  - projection of individual

- **Quarternary:**
  - burns, inhalation injuries
Mechanisms of Blast Injury

- **Primary Blast Injury**
  - Due to “blast overpressure” or “blast wave”
  - Rapid increase in air pressure due to an explosion.
  - Causes damage to air-filled cavities in the body.
  - Injuries to lungs, gastrointestinal tract, and ears
Mechanisms of Blast Injury

- **Secondary Blast Injury**
  - Results from flying objects or debris
  - May cause blunt head trauma or penetration
Mechanisms of Blast Injury

- Tertiary Blast Injury
  - Results when a body is thrown by blast “wind”, striking an object
  - Blunt head trauma, fractures, amputations
Mechanisms of Blast Injury

- **Quaternary Blast Injury**
  - Any other injuries such as burns, crushing
  - Inhalation of toxic materials
  - Exacerbation of existing disease states
These various mechanisms of blast injury can result in damage to the entire auditory system.
2. Potential Damage to the Auditory System from Blast Exposure
Potential Damage to the Auditory System from Blast Exposure

- **Peripheral**
  - Tympanic Membrane
  - Ossicular Chain
  - Cochlear Damage

- **Central**
  - Brainstem
  - Corpus Callosum
  - Temporal Lobe
  - Frontal Lobe

*Diagram showing the auditory system divided into outer, middle, and inner sections, with potential damage points noted.*
Peripheral Damage: Noise Exposure from Explosions/Weapons

- Intense and/or long duration sounds can permanently damage the cochlea.

- A few milliseconds of exposure to impulsive blast noise can cause damage equivalent to 10 years worth of noise exposure.
Peripheral Damage: Blast Pressure Wave and Flying Debris

- **Pinna damage:** Burns and shrapnel damage
- **Tympanic Membrane perforation:** Common otologic finding and recommended as a marker of blast exposure. (DePalma, 2005)
- **Ossicular disruption**
- **Cochlear damage:** 35-54% of blast injuries result in permanent sensorineural hearing loss.
Traumatic Brain Injury from Blast Exposure

- The central auditory system is one of the many brain systems at risk for blast injury.

- What is known about the locations and types of traumatic brain injury that can accompany blast exposure suggest that the auditory brain areas may be particularly vulnerable.
The Auditory Brainstem

Viewed from in front

Viewed from the midline
The Cortical System

Primary auditory cortex

Viewed from the side

Viewed from the midline
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*
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*
3. Organization and Functions of the Auditory Brain Areas and Potential Impacts of Damage
Connections are both
“bottom-up” (ascending)
and
“top-down” (descending)

Winer and Lee, 2007
Functions of the Auditory Brain Areas: Brainstem

- Cochlear nucleus regions extract timing and spectral information.
- Superior olivary complex codes binaural differences in time and level.
- Inferior colliculus codes information about modulation, binaural differences, and complex spectra.
Potential Impact of Thalamic and Brainstem Damage on Auditory Processing

- Reduced transmission of information, resulting in a lower neural “signal-to-noise” ratio.

- Binaural processing impaired through degraded timing of inputs to binaural comparison sites within the superior olivary complex.

- Modulation sensitivity reduced through damage to inferior colliculus and thalamus, resulting in reduced speech envelope processing.
Which Auditory Processing Tests Could be Used for Thalamic and Brainstem Damage?

Speech in Noise and Competing Speech Tests
- QuickSIN
- HINT
- Dichotic Digits

Localization and Spatial Processing Tests
- Binaural Masking Level Differences
- tests of localization accuracy

Temporal Modulation, Temporal Patterning and Spectral Contrast Tests
- Gaps In Noise Test
- Temporal or Spectral Modulation Functions
- Profile Analysis Tests
- Frequency Pattern Sequences Test
The “core” areas are tonotopically organized

The “belt” areas are non-tonotopic and/or multimodal

The other sensory systems and the limbic system connect directly to the auditory cortical regions

These cortical areas contain regions precisely tuned to specific attributes of sounds sources and auditory objects.

Winer and Lee, 2007
All areas of the ear-brain system are massively interconnected, but this is especially true of the auditory cortex and the thalamus.
Narain et al. (2003) using functional Magnetic Resonance Imaging (fMRI) found specialization for intelligible speech as compared to spectrally and temporally-matched non-speech stimuli.

The speech-specific areas were very well localized, suggesting that damage to such areas could produce profound effects due to a lack of redundancy in coding across the cortex.
Some areas are more active in auditory localization tasks than in auditory recognition tasks.

Maeder et al. (2001)
Other areas are more active in auditory recognition tasks than in auditory localization tasks.

Maeder et al. (2001)
Potential Impact of Temporal Lobe 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.
Which Auditory Processing Tests Could be Used for Temporal Lobe Damage?

- Staggered Spondaic Words tests
- Localization accuracy tests
- Gaps in Noise Test
- Dichotic Digits Test
- Frequency Pattern Sequences Test
Function of Frontal Lobe in Auditory Processing

Frontal lobe is connected to multiple regions of the temporal lobe and seems to be involved in cognitive processing and “top-down” attentional modulation of activity.
Hugdahl et al. (2003) found that activity in the temporal lobe can be modulated more strongly by the task the listener is performing than by the stimuli presented. Presumably, the frontal lobe mediates these effects.

In all of these cases, the stimuli presented were the same.
Potential Impact of Frontal Lobe Damage on Auditory Processing

- Decreased attentional focus.
- Decreased performance on tasks involving task-dependent selection and segregation of competing information.
Which Auditory Processing Tests Could be Used for Frontal Lobe Damage?

- Speech in competition (speech or noise)
  - QuickSIN
  - Dichotic Digits
- Attention to competing sounds?
- Informational masking?
Auditory Brain Area Summary

- **Auditory brainstem:** binaural, spectral, modulation, and other timing information.

- **Thalamus:** transmit and organize information.

- **Auditory cortex:** specialized processing of specific attributes of sound sources and auditory objects.

- **Damage to any of these areas can lead to substantial impairments even if peripheral function is unimpaired.**
4. Clinical Diagnosis and Treatment of Auditory Brain Injuries
The Rate of Central Dysfunction in Returning Veterans is Unknown

- Currently mandated TBI screening for returning veterans takes the form of a questionnaire rather than electrophysiological or behavioral tests.

- There is no electrophysiological or behavioral screening test for TBI or for central auditory dysfunction.

- There are no electrophysiological or behavioral tests for recovery of function for those diagnosed with central auditory dysfunction.
Challenges Associated With Testing for Auditory Processing Dysfunction in Veterans with Potential TBI

- Tests of auditory processing have been developed for and normed primarily on children.

For blast exposed listeners, we don’t know either the
- “Sensitivity” (chance of detecting existing dysfunction)
  or
- “Specificity” (chance of distinguishing among dysfunctions)
Behavioral Auditory Processing Tests

Most tests of central auditory processing can be characterized as testing one of the following areas (ASHA, 2005):

1) auditory performance in the presence of competing acoustic signals
2) temporal aspects of audition
3) auditory pattern recognition
4) auditory discrimination
5) auditory performance with degraded acoustic signals
6) sound localization and lateralization
Schow and Seikel (2007) report that few data exist showing the utility of screening in all of these areas. Further work is needed to determine whether or not such tests are useful for those exposed to blasts.

1) auditory performance in the presence of competing acoustic signals
2) temporal aspects of audition
3) auditory pattern recognition
4) auditory discrimination
5) auditory performance with degraded acoustic signals
6) sound localization and lateralization
Examples of Auditory Processing Tests

1) **Dichotic Digits** (Musiek, 1983)

- Assesses auditory processing in the presence of competing stimuli
- 4 numbers presented to both ears at comfortable listening levels.
- 2 numbers are presented to one ear and 2 numbers are presented to the other ear.
- The subject repeats all numbers that were heard.

<table>
<thead>
<tr>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex</td>
<td>80%[1]</td>
<td>80%</td>
<td>Resistant[2]</td>
</tr>
<tr>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Sensitivity and specificity for diagnosing various brain lesions, not specifically for diagnosing TBI.
Examples of Auditory Processing Tests

2) **Frequency Pattern Sequences Test**

(Musiek and Pinheiro, 1987)

- Assesses temporal patterning ability.
- Test items are sequences of three tone bursts that are presented to each ear independently.
- In each of the sequences, two tone bursts have the same frequency, while the third tone is a different frequency.
- Listener reports the order of the pitches (frequencies) on each presentation.

<table>
<thead>
<tr>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex</td>
<td>85%(cerebral)[3]</td>
<td>88% (cochlear vs. central)</td>
<td>Resistant[5]</td>
</tr>
<tr>
<td>Corpus callosum</td>
<td>45%(brainstem)[4]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brainstem</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Examples of Auditory Processing Tests

3) **Gaps in Noise Test** (Musiek et al., 2005)

- Assesses temporal resolution
- A series of six-second broadband noise segments are presented.
- Each noise segment contains 0 to 3 silent intervals (gaps).
- Gap durations are 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 milliseconds and are pseudorandomized with regard to their occurrence and location in the noise segment.

<table>
<thead>
<tr>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex</td>
<td>67%[6]</td>
<td>85%</td>
<td>Resistant[6]</td>
</tr>
<tr>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Examples of Auditory Processing Tests

4) **Binaural Masking-Level Difference (BMLD)**

(McFadden, 1975)

- Tests the integrity of the binaural processing system.
- Sensitive to lesions of the superior olivary complex in the brainstem.
- Thresholds for pure-tones determined in the presence of a masking noise.
- The noise is either in-phase or out-of-phase between the two ears.
- Thresholds for the pure tones should be improved when the masker is out-of-phase at the two ears.

<table>
<thead>
<tr>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brainstem</td>
<td>89%[7]</td>
<td>92%</td>
<td>May be compensated[8]</td>
</tr>
</tbody>
</table>

# 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>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dichotic Digits Test</strong></td>
<td>Cortex</td>
<td>80%[1]</td>
<td>80%</td>
<td>Resistant[2]</td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Frequency Pattern Sequences Test</strong></td>
<td>Cortex</td>
<td>85%(cerebral)[3]</td>
<td>88% (cochlear vs. central)</td>
<td>Resistant[5]</td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td>45%(brainstem)[4]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brainstem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corpus callosum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Binaural Masking Level Difference</strong></td>
<td>Brainstem</td>
<td>89%[7]</td>
<td>92%</td>
<td>May be compensated[8]</td>
</tr>
</tbody>
</table>


Sensitivity and specificity for diagnosing various brain lesions, not specifically for diagnosing TBI.
In addition to behavioral measures, it is possible to assess auditory processing with electrophysiological measures:

- Auditory Brainstem Evoked Response (Wave V latency)
- Long (or Late) Latency Responses (P300 latency and amplitude)

<table>
<thead>
<tr>
<th>Test</th>
<th>Probable Site of Lesion</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Influenced by mild-moderate hearing loss?</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABR (Wave V latency)</td>
<td>Brainstem</td>
<td>80%[9]</td>
<td>75%</td>
<td>Resistant/Compensable[10]</td>
</tr>
<tr>
<td>LLR (P300)</td>
<td>Cortex</td>
<td>80%[11]</td>
<td>70%</td>
<td>May be compensated[11]</td>
</tr>
</tbody>
</table>


Sensitivity and specificity for diagnosing various brain lesions, not specifically for diagnosing TBI.
Currently, there are no tests of auditory processing that make use of fMRI.

The fact that fMRI is an established tool for assessing temporal lobe function suggests that it would be ideal for tracking changes in auditory processing over time and could perhaps even be used for detecting deviations from normal function.
Challenges Associated with Using Auditory Processing Tests for Veterans Exposed to Blasts

- Unless tests of central auditory processing are used, deficits could be mistaken for PTSD, mental-health issues, and/or non-auditory cognitive deficits.

- The already complex task of auditory processing assessment is even more difficult in a TBI population because of confounding variables such as:
  - motivation
  - cooperation
  - emotional lability
  - noise toxicity
  - metabolic and circulatory changes
Challenges Associated with Using Auditory Processing Tests for Veterans Exposed to Blasts

- Despite these difficulties, anecdotal evidence from VA audiologists suggests that a significant number of those who have been exposed to blasts during combat have normal hearing sensitivity, yet still reported difficulties hearing speech, especially in background noise.

- As this is exactly the sort of deficit we would expect to see if the auditory brain were damaged, it is crucial that appropriate tests of central function are applied to this population.
How Do We Know Which Tests to Use?

- Very little research has been done on establishing the relationship between blast exposure and the incidence of central auditory processing disorders.

- In order to begin to address this problem, a new research program has been initiated by the NCRAR and Walter Reed Army Medical Center...
Measures of Central Auditory Processing Deficits Associated with Blast Exposure

Principle Investigators: Leek and Fausti
Co-Investigators: Walden and Lewis

Goals

- Obtain behavioral and neurophysiological measures of central auditory processing in soldiers returning from OIF/OEF following blast exposure

- Retest one year later to evaluate spontaneous recovery, ongoing problems, and delayed onset disabilities
Measures of Central Auditory Processing Deficits Associated with Blast Exposure

**Two groups** (matched for hearing loss, age and gender)
- Blast exposed and Non-blast-exposed

**Immediate and One-Year Follow-up Testing**
- Comprehensive Audiometric Evaluation
- Binaural Masking-Level Difference
- Gaps in Noise test
- Frequency Pattern Sequences Test
- Dichotic Digits test
- Staggered-Spondaic-Word test
- Auditory Brainstem Evoked Response
- Long Latency Responses
Questions to be Addressed

- Is there a significant difference in central auditory processing between patients with and without blast exposure?

- Which tests are most likely to provide indication of central disorders among the blast-exposed population, and what areas of the brain are most susceptible to auditory processing dysfunction, as reflected by performance on individual tests?

- Will patients who show some deficit on auditory testing experience a change of function after nine to twelve months?
The results of studies such as this one will help to guide clinical practice in the diagnosis and rehabilitation of auditory processing dysfunction in blast exposed veterans.
Treatment of Auditory Processing Dysfunction

Bottom-Up Approaches
- Amplification
- Auditory Training

Top-Down Approaches
- Compensatory Strategies

Environmental Modifications
- FM Systems, Sound Field Enhancements, Computer-based Tools
Treatment of Auditory Processing Dysfunction

- Each of these approaches (bottom-up, top-down, and environmental) is theoretically motivated, but currently unverified for TBI sufferers.

- Research is needed to determine which approaches work best and for which types of auditory processing dysfunction.

- Research is also needed on ways to evaluate the success of these interventions.
Summary

-The auditory brainstem, midbrain, thalamus and auditory cortex (including the frontal lobe) can all be damaged by exposure to blasts.

-Perhaps as important as damage to these processing areas, exposure to blasts can result in damage to connections among and within auditory brain areas.
Summary

- Damage to brainstem regions could impair processing of temporal, spectral, and binaural information.

- Damage to midbrain and thalamic regions could impair transmission of information and the formation of precisely tuned cortical receptive fields.
Summary

Behavioral tests:

1) auditory performance in the presence of competing acoustic signals
2) temporal aspects of audition
3) auditory pattern recognition
4) auditory discrimination
5) auditory performance with degraded acoustic signals
6) sound localization and lateralization
Summary

Electrophysiological tests:

- ABR: Wave V Latency
- LLR: P300 Amplitude and Latency
- Functional Magnetic Resonance Imaging (fMRI)
Research Challenges for the Future

- What are the sensitivity and specificity of various tests of auditory processing?
- What are the best interventions for confirmed auditory processing dysfunction?
- Which are the most reliable tests of the ways in which auditory processing ability changes over time?
Research Challenges for the Future

- How can auditory processing be assessed as rapidly as possible?

- What are the long-term effects of injury to the ear-brain system?

- How do central and peripheral damage interact?

- Does this interaction change over time and with age?
Thank You for Listening