Auditory Effects of Blast-Exposure in Service Members and Veterans

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The ability to hear is critical to success on the battlefield and in daily life.

2007- present DoD and VA Audiology Clinics reporting cases of Service Members with.....

- One or more blast exposures (roughly 80% of all casualties) 1-4
- Could have traumatic brain injury (TBI), 90% mild (“signature” wound, approximately 400,000 confirmed cases from 2000-2018) 1
- Clinically normal to near-normal hearing thresholds 2-4
- Report difficulty understanding speech in complex settings 1

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2 Saunders et al. (2015) JRRD: 99 of 99 (100%) blast-exposed
3 Lew et al. (2007a) JRRD: 16 of 42 (38%) blast-related TBI subjects
4 Lew (2007b) JRRD: 65% of VA Polytrauma Care patients
• Complaints from Service Members returning from combat include:
  • Listening in reverberant multi-talker environments or when speaker is talking fast
  • Following long conversations
  • Localizing sounds
  • Tinnitus
  • Sound sensitivity (hyperacusis)
  • Other non-auditory sensory issues (e.g., photophobia)
  • Dizziness
BACKGROUND: EVIDENCE OF ABNORMAL PERFORMANCE

STUDY 1
NCRAR/WRAMC (VA Funded)
44% of Blast-exposed Service Members (SMs) abnormal on CAPD measures
Binaural processing
Speech in Noise
Binaural integration
Behavioral & Evoked Potentials
Gallun et al. 2012

STUDY 2
WRNMMC (DMRDP/APHC Funded)
30% of Blast-exposed SMs abnormal on functional measures
Modified Speech, Spatial, and Qualities of Hearing
Binaural Integration
Speech in Noise
Binaural Processing (Quick SIN)
Brungart et al. 2014

STUDY 3
WRNMMC (CDMRP/DoD)
Blast-exposed SMs were less accurate localizing sounds with competing talkers than controls
CUNY sentences
3 Conditions
Quiet
1 Competing
2 Competing
Kubli et al. 2018

CLINICAL DATA
WRNMMC
110 Patients
55% Blast-exposed
70% Abnormal on combination of tests
63% Diagnosed with APD
Binaural Integration
Binaural Processing

Brungart et al. 2014
BACKGROUND: POSSIBLE REASONS

- Peripheral Distortion – Synaptopathy?
- Auditory Processing Disorder?
- Sensory Processing Disorder?
- Cognitive Processing Deficit?
  - Attention
  - Working memory
  - Speed of processing

Functional hearing and communication deficits (FHCD) in the presence of normal audiogram

Speech in Noise, Babble, and Reverberation:
What about Service Members (SMs) who Do NOT Seek Clinical Services?

Question: How large of a problem is this?

- SMs are required to get annual hearing exams to monitor their hearing using pure tone thresholds (audiogram)
- Audiogram is limited in how much it can tell us about hearing health
- Estimated number of SMs with similar problem understanding speech in complex noisy environments.
- Do SMs with noise and blast exposure history (training missions and deployments) have auditory issues?

Phase I: “Walter Reed Prevalence Study”

Apply auditory tests and subjective survey to Service Members during annual hearing checkup

Phase II: In-depth assessment of possible causes of functional deficits in blast-exposed individuals

- Auditory processing (evoked potentials, behavioral tests, auditory working memory, etc.)
- Cognitive deficits using visual and auditory tests (attention, memory, speed of processing etc.)

Phase I: Multi-site study conducted at Defense Occupational and Environmental Health Readiness System—Hearing Conservation (DOEHRSHC) clinics at:

- San Antonio Military Medical Center
- Naval Medical Center San Diego
- Walter Reed National Military Medical Center
Phase I:

1. Prevalence of SMs who report blast-exposure with normal or near-normal (H1 profile) and have difficulty understanding speech in noise

2. Examine the relationship between self-perceived communication difficulty, exposure to blasts, profile status, and performance on auditory screening measure (MLD/Speech-in-Noise)

* H1 Profile: Pure-tone average not more than 25 dB HL at 500 Hz, 1000 Hz, 2000 Hz with no individual level greater than 30 dB HL; 4000 Hz not over 45 dB HL
Some hearing loss allowed and still be profiled as H1

**H1: functionally normal or “fit for duty”**

PTA for each ear not more than 25 dB at .5, 1, 2 kHz with no individual level greater then 30 dB

≤ 45 dB at 4000 Hz

Grey stippled area must be resolved on a case-by-case basis

### Table 7-1 (shaded black region)

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Threshold (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
</tbody>
</table>

### H1 Profile (AR 40-501)

- H1: functionally normal or “fit for duty”
- PTA for each ear not more than 25 dB at .5, 1, 2 kHz with no individual level greater than 30 dB
- ≤ 45 dB at 4000 Hz
- Grey stippled area must be resolved on a case-by-case basis
1) Audiogram

2) Responses to Surveys
   - Demographic data
   - Self reported history of blast exposure
   - Subjective hearing performance from hearing survey
     (Modified Speech, Spatial, and Qualities of Hearing or modified SSQ)

3) Auditory Tests: Speech Reception Thresholds
   - Two tests of binaural integration: Binaural Masking Level Difference Test (MLD): $N_0S_0$ and $N_0S_{\pi}$ conditions
   - Two speech-in-Noise tests: Oldenburg Matrix Test (OMT)
     Sentences in background noise: Standard & Reverberation with speaking rate increased
Testing conducted using Android tablets platform with custom software and headphones

- Self-Administered
- Can be done anywhere: in the clinic, in the field
- Measure of functional communication ability rather than audibility (i.e., pure-tone thresholds)
- Abbreviated Consent Form

Data from DOEHRs-HC (hearing screening, age, and sex etc.) are coded and stored in an encrypted QR code

QR code is printed on the audiogram from a scanner connected to the DOEHRs HC

QR code is scanned into the tablet before or after testing

Information from DOEHRs HC may be manually added before or after testing

QR Code used to simplify and protect SM information
Oldenburg Matrix Test (OMT)

*Kathy gives nineteen old windows.*

<table>
<thead>
<tr>
<th>First</th>
<th>Second</th>
<th>Third</th>
<th>Fourth</th>
<th>Fifth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen</td>
<td>bought</td>
<td>two</td>
<td>cheap</td>
<td>chairs.</td>
</tr>
<tr>
<td>Doris</td>
<td>gives</td>
<td>three</td>
<td>dark</td>
<td>desks.</td>
</tr>
<tr>
<td>Kathy</td>
<td>got</td>
<td>four</td>
<td>green</td>
<td>flowers.</td>
</tr>
<tr>
<td>Lucy</td>
<td>has</td>
<td>seven</td>
<td>heavy</td>
<td>houses.</td>
</tr>
<tr>
<td>Nina</td>
<td>kept</td>
<td>eight</td>
<td>large</td>
<td>rings.</td>
</tr>
<tr>
<td>Peter</td>
<td>ordered</td>
<td>nine</td>
<td>old</td>
<td>sofas.</td>
</tr>
<tr>
<td>Rachel</td>
<td>prefers</td>
<td>twelve</td>
<td>pretty</td>
<td>spoons.</td>
</tr>
<tr>
<td>Steven</td>
<td>sees</td>
<td>fifteen</td>
<td>red</td>
<td>tables.</td>
</tr>
<tr>
<td>Thomas</td>
<td>sold</td>
<td>nineteenth</td>
<td>small</td>
<td>toys.</td>
</tr>
<tr>
<td>William</td>
<td>wants</td>
<td>sixty</td>
<td>white</td>
<td>windows.</td>
</tr>
</tbody>
</table>

**Condition 1: “OMT Standard”**
- Female target talker
- Spatially separated 4 talker babble
- Normal speaking rate
- SNR: 5, 2, 1, -4, -7, -10

**Condition 2: “OMT Speedy”**
- Female target talker
- Spatially separated 4 talker babble
- Speaking rate increased by 50% (66%-time compression); reverberation RT 60 time of .25 seconds
Subjects:

3398 active duty SMs tested with normal- to near-normal hearing thresholds

- Subjects were subdivided into 6 groups
- One time deployment to Iraq or Afghanistan (various branches of the military)

3 levels of blast severity

- No blast (NB)
- Blast far (BF)
- Blast close (BC)

2 levels of hearing thresholds

- Normal-hearing thresholds (NHT, ≤ 20 dB HL)
- Elevated-hearing thresholds (EHT)
Table I. The number and average age of listeners in the six listener groups. The number column also lists the number of male (M) and female (F) listeners in parenthesis, and the age column lists the mean ± one standard deviation across each group. NB=no-blast, BF=blast-far, BC=blast-close, NHT=normal-hearing thresholds, and EHT=elevated-hearing thresholds.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number (M/F)</th>
<th>Age [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB-NHT</td>
<td>1943 (1457/486)</td>
<td>26.4 ± 6.5</td>
</tr>
<tr>
<td>NB-EHT</td>
<td>542 (442/100)</td>
<td>30.3 ± 9.5</td>
</tr>
<tr>
<td>BF-NHT</td>
<td>313 (237/76)</td>
<td>34.4 ± 7.6</td>
</tr>
<tr>
<td>BF-EHT</td>
<td>170 (143/27)</td>
<td>38.2 ± 8.0</td>
</tr>
<tr>
<td>BC-NHT</td>
<td>235 (205/30)</td>
<td>35.2 ± 6.6</td>
</tr>
<tr>
<td>BC-EHT</td>
<td>195 (178/17)</td>
<td>38.2 ± 8.5</td>
</tr>
</tbody>
</table>
WALTER REED PREVALENCE STUDY: RESULTS

HL defined as any hearing threshold > 20 dB

Among subjects who were blast exposed, 41% had some degree of hearing loss

- History of blast exposure connected with loss of hearing in high-frequencies
- Self-reported high levels of noise exposure consistent with HL in ultra high-frequencies
• Risk factors:
  • Blast Exposure Level (3):
    • No blast (NB)
    • Blast far (BF)
    • Blast close (BC) – felt heat or pressure
  • Hearing Thresholds (2)
    • Normal hearing thresholds (NHT) ≤ 20 dB HL
    • Elevated hearing thresholds (EHT) – at least one hearing threshold ≥ 25 dB HL
  • Interaction Blast Exposure * Hearing thresholds
Comparison of non-clinical (Prevalence study participants) with clinical patients seen at WRMMMC (2013-2018) for further diagnostic testing using complex tasks (CAPD testing) N=200 all with H1 profiles.

Clinic patients with H1 profiles N=200; Non-clinical N=3398
Pure-tone audiogram and hearing profile does not predict performance on complex communication tasks

Estimated 33.6% blast-exposed SMs with thresholds >20 (H1) profile are at risk for auditory issues

Blast-exposed SMs (NH and HL) roughly 2-5 times as likely to perform abnormally on auditory measures than non-blast exposed SMs

HL and Blast-exposure may have a compounding effect on communication

Combination of quick tests may determine who requires further evaluation

Evaluation of communication ability requires a multi-level evaluation approach

End goal: Identify test battery and evaluate efficacy of intervention strategies
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WRNMMC-ASC
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• Charla Levy
• Erin N. Sheffer
• Jennifer L. Stidley

NMC-San Diego
• Erin Cesario
• Dana Cripps
• Carole R. Roth-Abramson


Mission: to improve the quality of life of Veterans and others with hearing and balance problems through clinical research, technology development, and education that leads to better patient care.
Auditory deficits are often **chronic**

- 30 Blast-exposed & 29 control participants, all with clinically normal or near-normal hearing sensitivity
- Average age = 37
- Average time since blast = 7 years
- Blast-exposed participants reported **significantly more hearing handicap** compared to controls

**Hearing Handicap Inventory for Adults:**
- **Significant:** 40%
- **Moderate:** 35%
- **None:** 25%
• **Auditory deficits are often chronic**
  

  – 63.3% Blast-exposed failed at least one auditory processing test
    – 37% failed 2 or more tests
  
  – Failures on tasks such as:
    – Temporal resolution
    – Pattern recognition
    – Binaural integration
    – Dichotic listening

![Graph showing the proportion of abnormal behavioral tests for blast-exposed and control groups.](image-url)
NEURAL CHANGES UNDERLYING AUDITORY DIFFICULTIES FOLLOWING BLAST EXPOSURE

• **Blast-related auditory difficulties could be related to:**
  – Damage/changes within the auditory pathway
  – Damage/changes in the brain affecting auditory and other functions
    • Other sensory pathways, post-concussive symptoms, PTSD, etc.
  – Damage/changes in cognitive pathways not specific to auditory function
Why Auditory Evoked Potentials?

- Distinguish where in the brain processing has been affected
  - Cochlea, Brainstem, Auditory Cortex, Cognitive areas
- Incredible temporal precision
- Non-invasive
- Often, no behavioral response required
  - Patients can sleep or watch movies
  - Removes cognitive/behavioral confounds
- Can be combined with behavioral response and paradigms testing cognition
- Clinical applications
• Cochlear Damage from blast overpressurization ("Hidden Hearing Loss")

• Hyper-excitability and increased neural noise in the auditory brainstem and cortex

• Loss of temporal precision in neural encoding
Noise exposure, including blast over pressurization, can lead to a significant amount of cochlear damage before hearing loss occurs.

**How?**
- Animal models reveal that noise is more damaging for auditory nerve fibers that code for higher-level sounds than to those that code for lower-level sounds.
- Does not occur immediately.
  - Synaptic loss worsens over time.

“HIDDEN” HEARING LOSS: EVIDENCE IN VETERANS

Wave I: Decreased input from the auditory periphery to the brainstem in noise-exposed Veterans

Waves III & V: Increased central “gain”, or compensation for reduced input

Associated with increased rates of tinnitus

• Cochlear Damage from blast overpressurization ("Hidden Hearing Loss")

• Hyper-excitability and increased neural noise in the auditory brainstem and cortex

• Loss of temporal precision in neural encoding
THE FREQUENCY FOLLOWING RESPONSE (FFR)

- Response of brainstem neurons to both transient and periodic components of sound
- An objective measure of how well the auditory system is encoding the timing and frequency information of speech and other sounds

• FFR in response to /da/:  
  – **Control**: 26 active SMs, no blast exposure or auditory difficulties

Grant et al. (2022) Functional hearing difficulties in blast-exposed service members with normal to near-normal hearing thresholds, Poster P64, SPIN conference
• FFR in response to /da/: 
  – **Control**: 26 active SMs, no blast exposure or auditory difficulties
  – **Blast**: 20 Blast-exposed SMs with auditory difficulties

• Results: 
  – Delayed neural response
  – Poorer neural signal-to-noise ratio
    • Noisy pre-stim baseline
  – Poorer encoding of pitch information

Grant et al. (2022) Functional hearing difficulties in blast-exposed service members with normal to near-normal hearing thresholds, Poster P64, SPIN conference

/da/ syllable:
• Cochlear Damage from blast overpressurization ("Hidden Hearing Loss")

• Hyper-excitability and increased neural noise in the auditory brainstem and cortex

• Loss of temporal precision in neural encoding
Auditory difficulties after blast exposure:

- Are prevalent
  - Approximately 1/3 of blast-exposed SMs at risk
- Are often chronic, and may worsen over time
- May stem from factors such as:
  - Cochlear damage (Hidden Hearing Loss)
  - Hyperactivity and increased “noise” in the central auditory pathway
  - Diminished neural temporal precision
Concussion Management Guidelines Neglect Auditory Symptoms

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(Clin J Sport Med 2022;32:82–85)

<table>
<thead>
<tr>
<th>Auditory Symptoms</th>
<th>Definition</th>
<th>Screening Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinnitus</td>
<td>Perception of sound in the absence of an external [acoustic] source.</td>
<td>Do you experience ringing in the ears (tinnitus) that lasts for at least 5 min?</td>
</tr>
<tr>
<td>Noise sensitivity</td>
<td>General intolerance to everyday sounds that encompasses a range of psychological attributes that contribute to the degree an individual is reactive to noise.</td>
<td>Do you have a problem tolerating sounds because they often seem too loud or bother you for other reasons?</td>
</tr>
<tr>
<td>Hearing difficulty</td>
<td>Trouble understanding speech or other sounds in quiet or noisy environments.</td>
<td>Do you have any difficulties understanding speech or other sounds? Do you feel like you have more difficulties hearing in noise compared with others?</td>
</tr>
</tbody>
</table>

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