Hearing Impairment and Tinnitus: Prevalence, Risk Factors, and Outcomes in US Service Members and Veterans Deployed to the Iraq and Afghanistan Wars

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Hearing loss and tinnitus are the 2 most prevalent service-connected disabilities among veterans in the United States. Veterans of Operations Enduring Freedom, Iraqi Freedom, and New Dawn have been exposed to multiple hazards associated with these conditions, such as blasts/explosions, ototoxic chemicals, and most notably high levels of noise. We conducted a systematic literature review of evidence on 1) prevalence of, 2) risk and protective factors for, and 3) functional and quality-of-life outcomes of hearing impairment and tinnitus in US Operations Enduring Freedom, Iraqi Freedom, and New Dawn veterans and military personnel. We identified studies published from 2001 through 2013 using PubMed, PsycINFO, REHABDATA, Cochrane Library, pearling, and expert recommendation. Peer-reviewed English language articles describing studies of 30 or more adults were included if they informed one or more key questions. A total of 839 titles/abstracts were reviewed for relevance by investigators trained in critical analysis of literature; 14 studies met inclusion criteria. Of these, 13 studies presented data on prevalence and 4 on risk/protective factors, respectively. There were no included studies reporting on outcomes. Findings from this systematic review will help inform clinicians, researchers, and policy makers on future resource and research needs pertaining to hearing impairment and tinnitus in this newest generation of veterans.

Hearing loss; prevalence; risk factors; tinnitus; veterans’ health

Abbreviations: CAPD, central auditory processing deficit; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom; OND, Operation New Dawn; PTSD, post-traumatic stress disorder; VA, Department of Veterans Affairs; VHA, Veterans Health Administration.

INTRODUCTION

Hearing loss and tinnitus (perception of sound in the absence of acoustic stimuli, i.e., ringing in the ears) have been consistently problematic for veterans and members of the military. These conditions are the top 2 service-connected disabilities for US veterans who have received a disability award from the US Department of Veterans Affairs (VA) (1). Understanding the epidemiology of hearing loss and tinnitus is a priority for both the US Department of Defense and the VA. Beyond compensation for disability awards, the Veterans Health Administration (VHA), a division of the VA, expends substantial resources providing clinical services to the nation’s veterans to address these conditions.

Recognizing the importance of this issue, Congress mandated that the VA contract with the National Academy of Sciences to review the data on hearing loss and tinnitus among service members in order to identify noise hazards in military service and the risk factors for noise-induced hearing loss (2). This effort resulted in a comprehensive publication titled, Noise and Military Service: Implications for Hearing Loss and Tinnitus (3). Principal findings of this report were that many military settings have noise levels of sufficient intensity and duration to cause hearing loss and that these same hazardous noise levels are associated with the development of tinnitus. Additionally, this report found that military hearing conservation programs were not effective in achieving their goal of preventing service members from developing noise-induced hearing loss (3).

Recent combat operations in and around Afghanistan and Iraq reflect the longest period of armed conflict the United States has engaged in since the Vietnam War. Operation
Enduring Freedom (OEF) began with military operations in Afghanistan in October 2001, and Operation Iraqi Freedom (OIF) began with military operations in Iraq in March 2003. Combat operations in Afghanistan are ongoing, while those in Iraq officially ended in August 2010. Effective September 2010, military operations in Iraq were termed Operation New Dawn (OND), reflecting a transition from combat to an advisory role. OND officially ended on December 15, 2011 (4). As of September 2013, the United States had deployed over 2.6 million service members to these 2 theaters of operations, nearly 1 million of whom have received VHA health care (5).

If outcomes in past veteran cohorts reflect current-day experiences, then hearing loss and tinnitus will be significant health problems in this newest generation of combat-deployed veterans. However, there is reason to believe that service in OEF/OIF/OND will be associated with even greater risks to hearing than did military service prior to these conflicts. The patterns of injuries with which these service members are surviving are different from those in previous wars (6). More service members are now surviving injuries on the battlefield (7), with the wounded-to-dead ratio being significantly higher than it was even during the Persian Gulf War of the 1990s (7–9). Approximately 75% of service members’ combat injuries result from blasts (10, 11) that, due in part to the physics of blast explosions, commonly inflict head injuries (11). Multiple VA research projects currently are examining the effects of blast-related traumatic brain injury (12); however, much remains unknown about the prevalence or effects of blast-related ear trauma or the effects of traumatic brain injury on the brain’s auditory processing abilities. Overall, there is limited information about the epidemiology of hearing impairment and tinnitus among US veterans and military service members who have served during these most recent conflicts.

The purpose of this review is to summarize the current evidence on hearing impairment and tinnitus in the newest generation of US combat veterans. Specifically, we sought to address the following key questions: Among US veterans and members of the military who served in OEF/OIF/OND:

1. What is the prevalence of hearing impairment and tinnitus?
2. What are the risk and protective factors for hearing impairment and tinnitus?
3. What are the effects of hearing impairment and tinnitus on functioning and quality of life?

**METHODS**

We conducted a systematic review of scientific literature addressing these key questions. Literature searches were conducted by using PubMed, PsycINFO, REHABDATA, and the Cochrane Library; our overall search was limited to peer-reviewed English language articles published from 2001 through 2013 that involved human subjects and had abstracts available. Search terms included 1) hearing loss (“hearing”; “hearing disorders”; “hearing loss”; “hearing tests”; “hearing aids”; “audiology”; “hearing injury”; “hearing trauma”; “hearing impairment”; “hearing sensitivity”; “audiological”; “auditory injury”; “auditory trauma”; “noise induced”; “dual sensory”; “hearing threshold”; “hearing conservation”; “hearing deficiency”); 2) tinnitus; 3) military (“military personnel”; “military medicine”; “hospitals, military”; “psychology, military”; “military facilities”; “military hygiene”; “military psychiatry”; “military science”; “military”; “army”; “marines”; “soldier”; “air force”; “navy”; “national guard”; “deployment”; “combat”; “active component”; “armed forces”); and 4) veterans (“veterans health”; “veterans”; “United States Department of Veterans Affairs”; “hospitals, veterans”; “veterans disability claims”). The results from each search were then merged to identify studies that included hearing loss, hearing problems, tinnitus, military, veterans, and any combination thereof. Additional articles were found by expert recommendation or by searching the reference lists of relevant studies.

**Inclusion/exclusion criteria**

This systematic review was restricted to studies involving US veterans and military service members who served in OEF/OIF/OND. This restriction enabled a synthesis of evidence pertaining to a relatively well-defined population and time period. Additionally, data on prevalence, risk/protective factors, and outcomes related to hearing impairment and tinnitus in this large population have significant implications for the US health-care system, particularly the VHA.

Studies that presented original data for this population, with a minimum sample size of 30, or that were systematic reviews were included. Narratives, letters, editorials, and commentaries were excluded. Studies that did not address the key questions or that did not differentiate either between veterans/military members who did versus did not serve in OEF/OIF/OND or between veteran/military and civilian populations were also excluded.

**Operational definitions**

Our initial intent was to synthesize evidence pertaining strictly to “hearing loss” among US veterans and military service members, as assessed by audiometric testing and/or indication that such tests had been used (i.e., medical record encounter data of diagnosis and procedure codes). Upon review of the current literature, however, we noted that newly emerging research in OEF/OIF/OND veterans is focused on blast-related injuries (e.g., traumatic brain injury) and associated health conditions, of which ear-related problems are one of many. Often, to establish the presence of hearing problems and auditory complaints associated with traumatic brain injury, self-report measures, rather than objective measures (e.g., audiometric testing), are used. This is an important distinction because blast waves can result in injury to auditory regions of the brain (e.g., central auditory processing deficits (CAPDs)) without subsequent damage to peripheral auditory structures. Blast waves can also cause damage to peripheral auditory structures that, after recovery (e.g., healed tympanic membrane perforation), does not result in permanent hearing loss. Therefore, in order to capture the prevalence of auditory dysfunction among US OEF/OIF/OND veterans and military personnel, we broadened the scope of our review to “hearing impairment,” with 2 operational definitions: 1) hearing loss identified from diagnostic audiometric results or from
any form of tinnitus (e.g., constant, recurrent, or intermittent). Therefore, our operational definition of tinnitus included all forms of assessment (e.g., self-report; ICD-9-CM diagnosis codes). These assessments often identify only the presence or absence of tinnitus and rarely evaluate whether the condition is constant or intermittent. Therefore, our operational definition of tinnitus included any form of tinnitus (e.g., constant, recurrent, or intermittent).

Data extraction and synthesis

A total of 839 titles and abstracts were identified and reviewed for relevance according to the above inclusion criteria by the first author. A secondary review of each title/abstract was conducted by at least one coauthor. Similarly, all full-text articles potentially meeting inclusion criteria were reviewed twice; the first author conducted the initial review and data extraction; a dual review was performed by at least one coauthor, and any discrepancies found between the review results were resolved through consensus prior to data synthesis. The reasons for exclusion of any articles were recorded and summarized.

For all studies that met the inclusion criteria, the following data were extracted: study design; sample size; collection dates; study setting; population; outcomes (e.g., hearing loss/problems or tinnitus); assessment method(s) for identifying outcomes; and prevalence or rate estimates. Because of the number of included studies utilizing restricted study samples (e.g., veterans with traumatic brain injury), we stratified results by whether data were ascertained from a population-representative sample versus a restricted sample and grouped studies accordingly in the resulting tables. The prevalence of dual sensory impairment (auditory and visual) was extracted given the frequency with which it was reported in the restricted sample studies. For studies reporting potential risk/protective factors or outcomes related to hearing impairment or tinnitus, we extracted assessment methods for the variables of interest, along with estimates of strength of association where available.

We critically analyzed studies to compare their results in context with study design and methods. The descriptive and heterogeneous nature of the included studies precluded the performance of meta-analyses. Our conclusions were drawn on the basis of qualitative synthesis of the reported findings. Studies with greater applicability to our aims in terms of study design, population, and assessment methods received greater emphasis.

RESULTS

Of the 839 titles and abstracts initially identified, 48 were pulled for full-text review (Figure 1). Of these, 14 met inclusion criteria (14–27). The most common reasons for exclusion were as follows: 1) did not include data relevant to US OEF/OIF/OND populations, or US OEF/OIF/OND individuals could not be differentiated from the rest of the sample population (n = 22); 2) did not meet the operational definition of hearing loss/problems (n = 8); and 3) nonsystematic reviews or commentaries (n = 4). Three additional articles were identified for full-text review through the reference lists of relevant studies, but they were excluded for similar reasons. Of the 14 articles meeting inclusion criteria, prevalence data were extracted and synthesized from 13 (14–26), and risk/protective factors

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**Figure 1.** Search results and final selection. Date range of included studies: 2005–2013. OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom; OIF, Operation Iraqi Freedom; OND, Operation New Dawn.
data were extracted and synthesized from 4 (14, 18, 20, 27); 3 studies are counted twice because the data reported on both prevalence and risk factors (14, 18, 20). None of the studies reported on functioning and quality-of-life effects of hearing impairment or tinnitus.

**Key question 1: prevalence of hearing impairment and tinnitus**

Table 1 summarizes the studies addressing prevalence of hearing impairment and tinnitus in US OEF/OIF/OND veterans and military personnel. Data are grouped according to the sample of individuals evaluated (i.e., representative of a larger veteran/military population (n=3) versus restricted samples (i.e., those reporting only on injured subgroups (n=10)). Among the more representative studies, prevalence of hearing problems ranged from 7.3% to 26.6% (14); hearing loss data (e.g., sensorineural hearing loss) demonstrated almost a tripling of reported cases from 2003 (0.8%) to 2004 (2.2%) with the rate of hearing loss remaining at 2.2% until 2009 (16). Helfer et al. (16) also reported an increase in the number of significant hearing threshold shifts (i.e., worsening of hearing thresholds from baseline measures) from <0.02% toward the beginning of the war to 5.0% in 2009. The prevalence of tinnitus was reported in 1 of the 3 studies and included a point estimate of 30.8% (15). Two of these studies involved retrospective reviews of Department of Defense medical records databases, while 1 involved review of VHA records; hearing impairment and tinnitus were identified by using ICD-9-CM diagnostic codes.

Frayne et al. (14) examined diagnosed hearing problems among OEF/OIF veterans who were using VHA services in 2006 and 2007; their primary purpose was to identify the burden of mental illness and its frequent comorbidities, including hearing problems, in this population. Proportions were stratified by gender and broken out by the presence of comorbid post-traumatic stress disorder (PTSD) diagnoses, other stress-related diagnoses, other mental health diagnoses, or no mental health diagnoses. The prevalence of “hearing problems” diagnosed among male veterans ranged from 16.4% to 26.6% and, among female veterans, from 7.3% to 13.4%. No information was provided on the specific diagnoses (i.e., objective or subjective) considered to represent “hearing problems.” It was noteworthy that, across all categories (e.g., those with PTSD diagnoses; those without PTSD diagnoses), males had approximately twice the prevalence of hearing diagnoses than females.

Helfer et al. (15) examined auditory diagnoses in a large sample of OIF soldiers who visited an Army audiology clinic between April 2003 and March 2004. Among those seen for problems related to deployment, 30.8% were diagnosed with tinnitus, while 29.3% were diagnosed with changes in hearing, identified by threshold shifts. Notably, 15.8% of this population was diagnosed with moderate to severe/profound hearing loss. A separate analysis by Helfer et al. (16) examined rates of change of hearing loss and tinnitus in OEF/OIF service members; results identified substantial underreporting of significant hearing threshold shifts from April 2003 through September 2006.

The restricted study samples primarily included veterans with deployment-related blast exposures, positive traumatic brain injury history, or both. Hearing impairment was assessed in multiple ways but most often involved clinical questionnaires or self-report patient questionnaires. The prevalence of hearing problems and loss was reported in 8 of the 10 studies (17–20, 22–25) and ranged from 11.6% (18) to 87% (22). Notably, relatively high proportions of most of these study samples reported some kind of hearing impairment. The prevalence of tinnitus was reported in 7 of these studies (17, 18, 21, 22, 24–26) and ranged from 6.1% (18) to 75.7% (22).

Oleksiak et al. (22) investigated auditory problems in OEF/OIF veterans diagnosed with mild traumatic brain injury (i.e., concussion) in a VHA medical center. Both audiometric and self-report measures were reported. On the basis of a retrospective chart review of the electronic medical records for these veterans, Oleksiak et al. identified a subset (n=75) who received a referral to audiology services following comprehensive evaluation for traumatic brain injury, at which time the Neurobehavioral Symptom Inventory had been administered. Overall, with inclusion of those veterans not referred to audiology services, self-reported hearing difficulty was reported for 87% of the entire sample.

Of the 75 veterans with mild traumatic brain injury who received an audiology referral, 37 attended their appointment. Of these 37 veterans, complaints of hearing problems were reported for 59.5% and tinnitus for 75.7% of the sample. Audiometric data were collected for 35 of the 37 veterans, and results identified hearing loss ranging from mild to moderate-severe in 32.4% of the sample (missing or incomplete audiometric data = 27.0%). It is noteworthy that audiometric results were found to be within normal limits in 35.1% of the sample. Central auditory processing deficits were confirmed in 16% (n=6) of the 37 veterans.

Similar to the study by Oleksiak et al. (22), 2 additional studies identified the prevalence of self-reported “hearing difficulty” as assessed during a comprehensive traumatic brain injury evaluation in national VHA samples (20, 24). Among those with confirmed traumatic brain injury history, 31% (20) and 61% (23) reported moderate or greater impact from their hearing difficulty. Cave et al. (17) evaluated OEF/OIF soldiers who were receiving treatment subsequent to blast injuries and found a high prevalence of hearing loss (58%), self-reported hearing problems (25.6%), and tinnitus (45.2%).

MacGregor et al. (21) reviewed encounter data (e.g., ICD-9-CM codes) associated with postdeployment health assessments and/or reassessments for OIF personnel who had sustained minor or moderate injuries while serving in Iraq between 2004 and 2008 and had a postdeployment health assessment within 1 year of injury. Their sample was restricted to military personnel diagnosed with mild traumatic brain injury or an injury other than to the head. Prevalence of tinnitus was reported to be 34.7% in personnel with mild traumatic brain injury and 17.9% in personnel with a non-head injury.

Wilk et al. (26) also reviewed medical records from US soldiers who served in Iraq during a similar time frame, 2006–2007. Their sample was restricted to those who served in combat with data recorded from 3 to 6 months postdeployment. US soldiers were surveyed by using patient health questionnaires assessing whether they had been injured during their deployment, focusing on postconcussion symptoms.
The prevalence of tinnitus was reported for 2 groups of soldiers with probable traumatic brain injury history occurring at the time of the injury: those who had lost consciousness and those who had an alteration in consciousness but did not lose consciousness. For the first group, the prevalence of tinnitus was 34.4% in those injured by a blast mechanism and 15.0% in those injured by a nonblast mechanism. For the second group, those who had altered consciousness, the prevalence of tinnitus was 22.2% in those injured by a blast and 17.0% in those injured by a nonblast mechanism.

Key question 2: risk and protective factors for hearing impairment and tinnitus

Table 2 summarizes the 4 studies (14, 18, 20, 27) that included information pertaining to risk or protective factors for hearing impairment and tinnitus in US OEF/OIF/OND veterans and military personnel. Three of these studies reported data from restricted-sample populations (18, 20, 27), and 1 study reported data representative of a larger veteran/military population (14).

Frayne et al. (14) evaluated comorbid mental health and hearing-related diagnoses among veterans seen for care in the VHA at least twice over a 2-year period. Stratified by gender, those with PTSD diagnoses had nearly 2 times greater odds of also having hearing-related diagnoses compared with veterans without any mental health diagnoses.

Dougherty et al. (18) reported on risk and protective factors by examining medical encounter data (e.g., ICD-9-CM codes) for OIF personnel who had sustained blast injuries to the ear while serving in Iraq from 2004 to 2008. This study was based on a review of Department of Defense databases for encounter data pertaining to hearing loss and tinnitus preinjury and within a year postinjury. Data on hearing protection status (i.e., whether worn or not) were reported. Results showed that, when hearing protection was worn at the time of blast injury, damage to peripheral ear structures and complaints of tinnitus were fewer in number compared with instances when blast-exposed military personnel were not wearing hearing protection. Of note was that the sample was almost equal in number of military personnel who were wearing hearing protection at the time of injury (48.9%) compared with those who were not (51.1%). In this sample, the odds of diagnosis for hearing loss within 1 year of the blast injury were associated with age, military branch, Injury Severity Score, history of head injury, and history of tympanic membrane rupture at the time of the blast. The odds of tinnitus diagnosis within 1 year were associated with age, Injury Severity Score, history of inner/middle ear injury involving tinnitus, and history of tympanic membrane rupture at the time of the blast.

Lew et al. (20) reviewed VHA and Department of Defense medical records from 2007 to 2009, examining symptoms of traumatic brain injuries sustained during deployment to Iraq and/or Afghanistan as reported on the Neurobehavioral Symptom Inventory. Dual sensory impairments of vision and hearing were examined on the basis of veteran self-report. A multiple linear regression analysis suggested that self-reported hearing difficulties were associated with age, sex, comorbid vision difficulty, traumatic brain injury history, and blast exposure. Further analysis revealed the best predictor of hearing difficulty was vision impairment.

Belanger et al. (27) evaluated US active duty military personnel and veterans with mild traumatic brain injury using the Neurobehavioral Symptom Inventory and found that hearing problems were associated with blast injuries. Belanger et al. suggest that tinnitus could have contributed to the complaints of hearing difficulties, but because tinnitus is not assessed as part of the Neurobehavioral Symptom Inventory, it was not possible to evaluate that association from their study.

Key question 3: outcomes of hearing impairment and tinnitus

Of the articles that met the inclusion criteria for this review, none evaluated the effects of tinnitus or hearing loss/problems on the functioning and quality of life among US OEF/OIF/OND veterans and military personnel.

DISCUSSION

Summary of literature addressing key questions

The majority of current evidence on hearing problems and tinnitus in US veterans and military personnel who served in OEF/OIF/OND focuses on injuries sustained in combat. The review of articles meeting our inclusion criteria demonstrated that auditory complaints, such as hearing loss/problems and tinnitus, are highly prevalent, and in some injured populations, greater than 50% (17, 22–24). In the studies that reported on more representative populations (i.e., population-based samples of individuals seeking care in the Department of Defense or VHA health-care systems), target populations and outcomes were distinct and therefore not readily comparable. However, it is notable that, among more than 90,000 OEF/OIF veterans seen in the VHA system of care (a relatively representative sample of VHA-using OEF/OIF/OND veterans), 16.4%–26.6% of men and 7.3%–13.4% of women were diagnosed with hearing problems (14).

Risk/protective factors for hearing problems, while preliminary, appear to include age, gender, military branch and component, blast exposure, PTSD diagnoses, and characteristics of initial injuries. It is likely that some of these factors indirectly affect the onset of auditory complaints through their associations with high-risk combat exposures and other postdeployment health problems; however, research differentiating causal factors from other correlates in representative samples of OEF/OIF/OND veterans has not yet been published and is greatly needed. For example, we found no studies (that met our inclusion criteria) evaluating the potential effects of medications or other chemical exposures on auditory dysfunction in this population. Similarly, the literature is limited as to the effects of hearing impairment and tinnitus on the functioning and quality of life for this population.

Overall, of all the studies included in this review, the majority reported data collected from treatment-seeking veterans and military personnel. Therefore, these data may not be generalizable to the entire OEF/OIF/OND population and might...
<p>| First Author, Year (Reference No.) | Study Design | Sample Size, No. | Collection Dates, Years | Study Setting | Population | No. of Males | % Male | No. of Females | % Female | Age, Years | Outcomes | Assessment Methods | Prevalence or Rate Estimates |
|-----------------------------------|--------------|-----------------|-------------------------|--------------|------------|--------------|--------|--------------|----------|------------|----------|------------------|-----------------------------|-----------------------------|
| Frayne, 2011 (14)                 | Retrospective medical records review | 90,558 | 2006–2007 | National VHA outpatient care records for OEF/OIF veterans seen in VHA twice within 2 years, comparing veterans with mental health diagnoses with those without mental health diagnoses | 77,727 | 86 | 12,831 | 14 | &lt;25–≥40 | Hearing problems, Mental illness: 1) PTSD; 2) other, stress related; 3) other mental health diagnoses | ICD-9-CM codes | Self-reported “hearing problems” in those with the following 4 diagnoses—1) PTSD diagnosis: males = 26.6%; females = 13.4%; 2) other stress-related diagnoses: males = 22.4%; females = 10.3%; 3) other mental health diagnoses: males = 16.4%; females = 7.5%; 4) no mental health diagnoses: males = 16.6%; females = 7.3% |
| Helfer, 2005 (15)                 | Retrospective medical records review | 806 | 2003–2004 | DoD military health system records of OIF soldiers (active duty, National Guard, reserves) seen in Army audiology clinics and diagnosed with postdeployment-related problems | 123,595 | 87 | 18,254 | 13 | &lt;25–≥55 | Hearing threshold shift. Hearing loss. Tinnitus | ICD-9-CM diagnosis and V-codes (from encounter data) | Permanent threshold shift = 29.3%; moderate-to-severe profound hearing loss = 15.8%; tinnitus = 30.8% |
| Helfer, 2011 (16)                 | Retrospective medical records review | 804,535 | 2003–2009 | DoD military health system records of OEF/OIF service members (active duty) seen during deployment or within 6 months postdeployment | 725,103 | 90 | 79,432 | 10 | 17–≥55 | Hearing loss. Hearing threshold shift | ICD-9-CM codes | 2003 SNHL = 811/100,000 (0.8%); 2004–2009 SNHL = 2,200/100,000 (2.2%); 2009 significant threshold shift = 5,000/100,000 (5.0%); significant threshold shifts underreported in 2003–2006 |</p>
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<tr>
<th>First Author, Year (Reference No.)</th>
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<th>Population</th>
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<td>21,627</td>
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<td>VHA and DoD medical records data for veterans evaluated for TBI; TBI history: 12,521 (58%)</td>
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<td>MacGregor, 2013 (21)</td>
<td>Retrospective medical records review</td>
<td>992&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2004–2008</td>
<td>Expeditionary Medical Encounter Database queried for OIF personnel who completed a postdeployment health assessment within 1 year of sustaining minor/m moderate injuries in Iraq</td>
<td>946</td>
<td>95</td>
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<td>Oleksiak, 2012 (22)</td>
<td>Retrospective medical records review</td>
<td>240</td>
<td>2007–2009</td>
<td>Veterans with mild TBI and hearing problems seen at 1 VA site</td>
<td>221</td>
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<td>2007–2009</td>
<td>VHA and DoD records for veterans with TBI</td>
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<td>Retrospective medical records review</td>
<td>436</td>
<td>2003–2006</td>
<td>OEF/OIF military personnel wounded in combat; treated at 1 military medical facility</td>
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<td>Wilk, 2010 (26)</td>
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<td>2006–2007</td>
<td>OIF soldiers (active duty and National Guard) 3–6 months postdeployment</td>
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<td>98.3</td>
<td>No. of Females % Female</td>
<td>Tinnitus</td>
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Abbreviations: CAPD, central auditory processing deficits; DoD, Department of Defense; ICD-9-CM, *International Classification of Diseases, Ninth Revision, Clinical Modification*; OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom; OND, Operation New Dawn; PTSD, post-traumatic stress disorder; SD, standard deviation; SNHL, sensorineural hearing loss; TBI, traumatic brain injury; VA, Department of Veterans Affairs; VHA, Veterans Health Administration.

* Mean = 28.9 years.
* Mean = 24.0 (SD, 5.3) years.
* Mean = 27.3 years.
* FIM (known as “Functional Independence Measure” until becoming proprietary; Uniform Data System for Medical Rehabilitation, a division of UB Foundation Activities, Inc., Amherst, NY).
* Mean = 31.3 years.
* The total of 992 comprises 334 mild TBIs and 658 nonhead injuries.
* Mean = 27.9 years (at examination).
* Mean = 31.4 years.
* Mean = 27 years.
* Mean = 28.0 (SD, 9) years.
help explain the relatively high prevalences of hearing difficulties and tinnitus across studies. In this systematic review, 7 articles were restricted to individuals with blast exposure (17–20, 24–26), 2 were additionally restricted to individuals with positive traumatic brain injury history (21, 22), and 2 were additionally restricted to blast exposure and traumatic brain injury history (19, 20). These studies represent subsets of treatment-seeking populations. No studies were found that are representative of the entire OEF/OIF/OND population.

Because of comorbid health problems that are frequently associated with blast exposure and traumatic brain injury, it is difficult to know the degree to which these concomitant problems influence each other, including hearing problems and tinnitus. Another complicating factor is that the best method(s) to measure and assess postdeployment health problems is not well established. For example, the Neurobehavioral Symptom Inventory is often administered as part of a comprehensive traumatic brain injury evaluation. Its purpose is to document deployment-related postconcussive symptoms. Research has shown both strong and weak correlations between the self-report complaints and diagnostic tests of the same domains (28), suggesting that the Neurobehavioral Symptom Inventory may have limited sensitivity as an assessment tool for the variety of impairments of interest.

Our work highlights the challenges inherent to measuring and reporting audiological problems at the population level. Objectively quantifying auditory problems is difficult because it requires in-person assessment with trained clinicians; furthermore, the standard audiological test battery does not always detect or diagnose the hearing difficulties that tend to be reported by this population. For example, service members’ audiometric results might not be sensitive to changes that have occurred following deployment. Test results might technically be within normal limits (i.e., normal hearing sensitivity), yet it is possible that hearing thresholds have worsened, just not to the degree necessary to be classified as “impaired.” This scenario could explain the results reported in one study (22) of veterans who reported hearing problems, but audiometrically were “normal” (35.1% of the sample). In this instance, examining hearing threshold shifts might explain the perceived hearing “problem,” because a significant hearing threshold shift can occur in situations where measured thresholds are still within the normal range; the Department of Defense defines a significant hearing threshold shift as “a change in hearing threshold relative to the initial reference audiogram of an average of 10 dB or more at 2,000, 3,000, and 4,000 Hz in either ear” (29, p. 15).

Veterans’ health care: addressing auditory complaints

Tinnitus and hearing loss are the 2 most prevalent service-connected disabilities for all veterans. Tinnitus often occurs as a consequence of damage to the auditory system following noise exposure and other causes of hearing loss. Peripheral auditory dysfunction commonly occurs following blast exposure (17–20, 24, 30); therefore, the high prevalence of tinnitus reported among US OEF/OIF/OND veterans and military service members exposed to blasts is not surprising (17, 24). Previous work has shown that veterans have a higher prevalence of tinnitus compared with nonveterans. Folmer et al. (31) analyzed population-based data collected from the National Health and Nutrition Examination Survey and found that the prevalence of self-reported tinnitus was more than 2 times greater among veterans than among nonveterans. An established relationship exists between hearing loss and tinnitus. It is not uncommon for individuals to incorrectly blame their communication difficulties on tinnitus rather than the underlying hearing loss (32–34). In situations where hearing loss and tinnitus both exist, amplification (i.e., hearing aids) can be beneficial; not only do hearing aids facilitate improved communication, but they can also help to reduce some tinnitus-related problems (32, 35, 36). When amplification alone is not sufficient to resolve all tinnitus-related problems, tinnitus management should be considered as the next step in treatment (32). It is likely that the VHA and other health-care organizations that serve OEF/OIF/OND veterans will need to increase capacity to maximally address veterans’ hearing problems and tinnitus management needs over the years to come. Some work has suggested that the auditory complaints of blast-exposed military personnel and veterans appear to be unlike complaints reported among those who were not exposed to blasts (37, 38). Although these studies did not meet the inclusion criteria for our review, their findings are important to place into context with our results. Hearing loss, by definition, is impairment in one’s ability to detect the presence of sound. Gallun et al. (37) demonstrated that, while many blast-exposed veterans may have essentially normal audiometric thresholds, they may exhibit CAPD, including difficulties understanding speech in noisy environments. These deficits may be caused by damage to neural structures (including the auditory cortex, corpus callosum, and other neuronal pathways) during blast exposure. In their study, participants in a blast-exposed group were 10 times more likely than non–blast-exposed controls to exhibit abnormal results on tests of central auditory function, suggesting that the auditory complaints seen in this population might be due to deficits in the central auditory system. Papesh et al. (38) recently reported that CAPD appears to persist for some veterans 8 years or longer after blast exposure. Because of the frequency of blast exposure in the current era of warfare, CAPD and other types of auditory dysfunction may be a significant problem among OEF/OIF/OND and future veteran cohorts.

Among individuals with history of traumatic brain injury, often there are multiple comorbid health issues, making it difficult to parse out the degree to which each of the various problems contributes to veterans’ overall functional impairment. To capture all of the potential health problems experienced by this population, including hearing-related problems, Fausti et al. (39) supported taking a multidisciplinary approach and performing comprehensive audiological evaluations expanding on the standard test battery to include tests of central auditory functioning. Often the central auditory problems experienced by this population are difficult to diagnose and, as Fausti et al. point out, “The already complex task of CAP [central auditory processing] assessment is even more difficult in the traumatic brain injury population because variables such as motivation, attention, cooperation, cognition, neuronal loss, noise toxicity, metabolic and circulatory changes,
Table 2. Details of Included Studies Reporting Information About Risk or Protective Factors for Hearing Impairment or Tinnitus Among US OEF/OIF/OND Veterans, by Study Sample Type, 2011–2013

<table>
<thead>
<tr>
<th>First Author, Year (Reference No.)</th>
<th>Study Design</th>
<th>Sample Size, No.</th>
<th>Collection Dates, Years</th>
<th>Study Setting</th>
<th>Population</th>
<th>Outcomes</th>
<th>Assessment Methods</th>
<th>Potential Risk/Protective Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frayne, 2011 (14)</td>
<td>Retrospective medical records review</td>
<td>90,558</td>
<td>2006–2007</td>
<td>National VHA outpatient care records for OEF/OIF veterans seen in VHA twice within 2 years, comparing veterans with mental health diagnoses with those without mental health diagnoses</td>
<td>77,727</td>
<td>86</td>
<td>12,831</td>
<td>14</td>
</tr>
<tr>
<td>Belanger, 2011 (27)</td>
<td>Case series</td>
<td>390</td>
<td>Years unknown</td>
<td>Active duty service members and veterans with history of mild TBI seen at 1 military medical facility or 1 of 2 VHA sites</td>
<td>94</td>
<td>6</td>
<td>—a</td>
<td>Hearing problems</td>
</tr>
<tr>
<td>Lew, 2011 (20)</td>
<td>Retrospective medical records review</td>
<td>21,627</td>
<td>2007–2009</td>
<td>VHA and DoD medical records data for veterans evaluated for TBI; TBI history: 12,521 (58%)</td>
<td>20,306</td>
<td>94</td>
<td>1,319</td>
<td>6</td>
</tr>
</tbody>
</table>

Table continues
<table>
<thead>
<tr>
<th>First Author, Year (Reference No.)</th>
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<th>Outcomes</th>
<th>Assessment Methods</th>
<th>Potential Risk/ Protective Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dougherty, 2013 (18)</td>
<td>Retrospective medical records review</td>
<td>3,981</td>
<td>2004–2008</td>
<td>Blast-injured OIF personnel (Army, Navy, Marine Corps, Air Force)</td>
<td>3,930</td>
<td>99</td>
<td>51</td>
<td>1</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; DoD, Department of Defense; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; OEF, Operation Enduring Freedom; OIF, Operation Iraqi Freedom; OND, Operation New Dawn; OR, odds ratio; PTSD, post-traumatic stress disorder; SD, standard deviation; SE, standard error; TBI, traumatic brain injury; VHA, Veterans Health Administration.

a Blast injured: mean = 28.3 (SD, 7.9); nonblast injured: mean = 30.0 (SD, 9.1).
b Mean = 31.3.
c Mean = 24.0 (SD, 5.3).
working memory, and other comorbid factors can confound test interpretations and cause misdiagnosis” (39, pp. 802–803).

Traumatic brain injury is considered the “signature injury” of the OEF/OIF/OND conflicts (40, 41). Military service members with traumatic brain injury history often report poorer health outcomes (e.g., PTSD, substance abuse) compared with those without this injury history (40). One ramification of the prevalence of traumatic brain injury in this large cohort is that the number of individuals pursuing VHA health-care services will likely continue to increase in the coming years. There will also be an increased need for a multidisciplinary approach to manage these veterans’ complex health-care and rehabilitation needs.

Hearing conservation programs

Hearing loss and tinnitus secondary to noise exposure are preventable. Hearing conservation programs exist in all branches of the military, but the effectiveness of these programs is limited. One reason for this limited effectiveness is unreliable implementation of hearing conservation program recommendations among military service members. The Department of Defense hearing conservation program, which is similar to hearing conservation programs in private industry, outlines “best practices” such as monitoring and identifying noise exposures, use of hearing protectors, audiometric testing, and program evaluation; however, enforcement of these best practices is often inconsistent (29).

In addition to hearing conservation programs, standards have been created in an attempt to minimize risk of hearing impairment and injury occurring when certain noise limits are exceeded. The Department of Defense standard known as MIL-STD-1474D outlines criteria specific to design matériel and states, “This standard is neither a hearing damage risk criterion nor a hearing conservation criterion. It is a set of design criteria . . . more stringent than Occupational Safety and Health Administration (OSHA) standards [for certain types of noise particularly in regards to impulse noise] and will be used in lieu of OSHA standards (29 CFR 1910.95)” (42, p. ii). MIL-STD-1744D is based on established data from multiple documents—AFOSHSTD 48-19: Hazardous Noise Program; DA PAM 40-501: Hearing Conservation; 29 CFR 1910.95: Occupational Noise Exposure; OPNAVINST 5100.23B: Navy Occupational Safety and Health Program Manual; and OPNAVINST 5100.19B: Navy Occupational Safety and Health Program Manual for Forces Afloat (42, p. 9). This standard establishes guidelines to inform hearing conservation criteria in an effort to minimize “hearing damage risk” associated with various types of noise (e.g., continuous vs. impulse noise).

Additional prevention measures may be needed to reduce the negative effects of blasts. One study found that wearing hearing protection was beneficial in reducing the number of reported cases of tinnitus and peripheral ear damage secondary to blast exposure (18); however, the literature is limited concerning the extent to which hearing impairment and tinnitus secondary to blast exposure can be prevented. This will be an important area of study in the years to come. Future work might consider the effectiveness of military hearing conservation programs across different countries, for example, investigating if differences exist in hearing protection strategies as a function of country and whether the US military would benefit from implementing the different strategies identified.

Medical cost of war

The United States has been at war in Afghanistan longer than any other war in American history (43). As VA disability claims continue to increase, the medical costs for OEF/OIF/OND veterans also may increase. In addition to the costs for primary injuries (e.g., amputation, traumatic brain injury), the costs incurred for secondary and tertiary injuries are mounting (44). Secondary injuries include tinnitus, noise-induced hearing loss, and central auditory dysfunction (e.g., CAPD).

Current guidelines for VA compensation do not include CAPD and the resulting communication difficulties as part of the definition of hearing impairment. New guidelines and policies may need to be developed to account for injuries such as CAPD that are not routinely evaluated.

Limitations

This systematic review had several limitations that should be taken into context with our results. First, findings were limited by the operational definition selected to represent hearing loss. By broadening our definition to “hearing problems” and including data from self-report questionnaires, we found it difficult to assess the “degree” of hearing problems and therefore to compare results across studies. Data collected from objective measures (e.g., audiograms) cannot easily be compared with data collected from subjective measures (e.g., questionnaires). As such, it was difficult to assess the validity of self-report measures used across studies. Another factor is that not all of the instruments used across studies have similar phrasing of questions, and often limited information was available as to the process of implementing the questionnaires or hearing health evaluations. Similarly, it is unknown to what extent clinicians and others assessing auditory problems do so accurately, especially because the current measures used might not be sensitive to detecting and diagnosing the new trends in veterans’ complaints (i.e., CAPD). This issue, as well as errors in assigning ICD-9-CM codes, could contribute to misclassification in some of the studies included in our review.

Use of ICD-9-CM codes for epidemiologic research has been shown to introduce systematic bias (45, 46). Future studies are needed to quantify the magnitude and direction of potential misclassification bias on studies evaluating auditory disorders in combat veterans. However, use of these codes in large administrative databases can be an efficient, albeit preliminary, method to quantify potential problems on a population level, at least among those receiving medical care. Almost all of the included studies involved retrospective chart reviews; there is always a question regarding the accuracy of reported ICD-9-CM codes when querying medical records databases. Even when ICD-9-CM codes are entered correctly, it is possible that the person entering the code may not have selected the most accurate code for the diagnosis or procedure performed.
Finally, this review included a number of studies with restricted sample populations. This limits some of the conclusions that can be made on the basis of these data; however, these studies also represent an important subgroup of the OEF/OIF/OND veteran population that warrants special focus. Prior to the conflicts in Iraq and Afghanistan, the literature on auditory problems associated with blasts examined outcomes of terrorist attacks (47, 48). Many of the blast-related injuries to the auditory system (including hearing loss and tinnitus) are similar to those reported in this review because they are associated with exposure to an explosive device (47, 48); future work might synthesize evidence across combat and noncombat blast-exposed populations. Consistency in how secondary and tertiary injuries (e.g., hearing impairment, tinnitus, CAPD) are identified and measured will be necessary to better understand the impact of these comorbid problems after blast exposure.

Conclusions

This systematic review summarizes the current knowledge regarding prevalence of, risk factors for, and outcomes of hearing impairment and tinnitus in the US population of OEF/OIF/OND veterans and military personnel. Given this, to our knowledge, the first such review, we believe our broader operational definitions of hearing problems and tinnitus served as a strength by allowing us to consider additional, potentially informative data that would otherwise have been excluded. This is particularly important given that some self-reported hearing problems are not detected via audiometric testing.

Several studies included in this review combined tinnitus with other “hearing problems,” making it impossible to differentiate the prevalence of tinnitus from other hearing-related disorders. In order to better understand the prevalence and risk factors for hearing impairment and tinnitus, future studies ideally will use assessment methods that are more concise in defining what constitutes these conditions. Greater consistency in definitions and assessment methods across future studies would allow for better comparability and, ultimately, meta-analyses to be performed.

Another important finding from this systematic review is that the effects of hearing problems and tinnitus on OEF/OIF/OND veterans are relatively unknown. Hearing problems and tinnitus are often reported as complaints, but literature evaluating their impact on the quality of life or functioning of this population has yet to be published. Much more research is needed to fully understand the lasting effects of the recent wars on the 2.6 million US service members and veterans who were deployed during this time.

Future studies, emphasizing robust, longitudinal research, are necessary to 1) compare the prevalence and risk factors for hearing impairment and tinnitus in veterans from other countries with the population considered in this systematic review; 2) better understand how hearing protection used during combat and training might reduce auditory injuries (including tinnitus); 3) elucidate noise and other risk factors for auditory problems, disentangling them from confounding variables; and 4) evaluate the long-term persistence and outcomes of all auditory complaints, including tinnitus and CAPD, in this newest generation of veterans.

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