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### Noise:

#### Acoustic Trauma and Tinnitus, the US Military Experience

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### Keywords

Tinnitus; Noise; Ototoxicity; Hearing disorders; Hyperacusis

## INTRODUCTION

It is well established that noise exposure is a risk factor for military personnel, Veterans, and civilians to develop tinnitus.<sup>1,2</sup> In 2010, the US Department of Health and Human Services announced an initiative called Healthy People 2020, which aims to improve the overall health of individuals living in the United States by the year 2020.<sup>3</sup> One of the goals of Healthy People 2020 is to reduce the prevalence and severity of auditory disorders. In their midcourse review, it was noteworthy that compared with data from 2005 to 2006, adolescents' (aged 12–19) use of hearing protection when exposed to loud noise in 2009 to 2010 had worsened. The midcourse review also highlighted that compared with 2007, which revealed 44.5% of adults (aged 18) sought advice from a doctor about their tinnitus, in 2014 the percentage had increased to 48.5%. Additionally, in 2014, 61.8% of adults (compared with 45.8% in 2007) reported tinnitus severe enough in the last 5 years to have seen an otolaryngologist or audiologist. Unfortunately, only 14.7% of the 45.8% of adults in 2007 who sought medical advice for bothersome tinnitus, reported trying any form of treatment. Overall, these data suggest that it is necessary to improve outreach efforts to inform as many individuals and groups as possible about the extent of noise-induced damage to the auditory system and the importance of taking preventative measures.

The purpose of this article is to increase the medical community's awareness of the multifaceted nature of noise-induced tinnitus, focusing on the experience of military personnel and Veterans, and to provide a clinical decision-making guide that can support effective referrals and resources to help patients manage their tinnitus. A related goal is to increase awareness that military, occupational, or recreational exposures to high noise levels,

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#### DISCLOSURE

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particularly firearm use, can exacerbate auditory injury from commonly used ototoxic drug therapies, further increasing the risk of incident tinnitus and hearing loss resulting from independent exposure to either of these damaging agents.

Noise exposure is a major public health concern that negatively impacts numerous health systems resulting in auditory deficits (hearing loss, tinnitus) and nonauditory consequences (sleep disturbances, annoyance, cardiovascular disease<sup>4</sup>). A recently published article by Kerns and colleagues<sup>5</sup> found noisy work conditions were associated with high blood pressure, high cholesterol, and hearing difficulty. In general, “noise” refers to unwanted sound and “noise exposure” typically refers to exposure to hazardous levels of any type of sound that can result in hearing loss.<sup>4</sup>

The National Institute for Occupational Safety and Health has published standards for permissible occupational noise exposure for an 8-hour workday not to exceed 85 to 90 dBA.<sup>6</sup> A limitation of current industrial standards is that they severely underestimate the effect of exposure to short-duration sounds. For example, the output of military weapons far exceeds these permissible levels and are approximately 150% higher than published acceptable standards.<sup>7</sup> Noise-induced hearing loss is preventable, and yet to date, has remained a major health burden in the United States and worldwide affecting billions of individuals.<sup>8-10</sup>

Military personnel and Veterans are exposed in training and during their military service to levels of noise that results in hearing loss and tinnitus.<sup>1,11,12</sup> Noise-induced tinnitus and hearing loss are so pervasive they have remained the top two service-connected disabilities for Veterans receiving compensation for more than a decade.<sup>13</sup> The perception of tinnitus is often associated with elevated hearing thresholds, but an important caveat is that noise-induced tinnitus can occur in the absence of hearing loss measured through conventional pure-tone audiometry and by itself, is suggestive of pathologic injury to the auditory system.<sup>14</sup> Studies in humans have demonstrated important relationships between tinnitus and reduced auditory nerve activity as assessed using auditory brainstem response wave I,<sup>15</sup> or the acoustic reflex,<sup>16</sup> after statistically adjusting for variations in outer hair cell function using otoacoustic emissions. This is broadly consistent with results in animal models of tinnitus that demonstrate reduced peripheral input causes enhanced neural activity in the central auditory system, that is, increased central gain,<sup>17</sup> which can occur in response to damage at the level of the inner hair cells and auditory nerve.<sup>18,19</sup>

In general, Veterans are twice as likely to have tinnitus compared with non-Veterans and exposure to loud sounds during their military service is a major contributing factor to this outcome.<sup>20</sup> Data regarding the prevalence and impact of tinnitus on military Service Members are less known. This gap in knowledge was recently addressed by Henry and colleagues<sup>21</sup> who showed that 34% of Service Members (n = 182) had constant tinnitus and 44% of Veterans (n = 246) had constant tinnitus. Service Members with tinnitus reported negative consequences similar to Veterans, such as difficulty with concentration, job performance, sleep, and emotional well-being.<sup>21</sup>

Additionally, previously identified risk factors for tinnitus in Service Members and Veterans include age; sex; blast exposure; and co-occurring mental health conditions, such as post-traumatic stress disorder (PTSD).<sup>1</sup> Of note, Veterans who served in Iraq and Afghanistan (Operations Iraqi and Enduring Freedom/New Dawn, respectively) are at increased risk for major depression, anxiety disorders, and PTSD.<sup>22</sup>

The adverse functional and psychosocial impacts of tinnitus and the benefit of treatment are illustrated in the video case example found on the National Center for Rehabilitative Auditory Research's Web site (<https://www.ncrar.research.va.gov/PatientVoices/Index.asp>). The video introduces you to Brian, a 40-year-old Veteran with bothersome tinnitus that he describes as "hell," an "invisible disability" that "affects [his] well-being and way of life." He was interested in participating in tinnitus research to learn ways to cope with his tinnitus. He reported a history of high noise exposure including from weapons fire and aircraft engines, having spent most of his 4-year military tour aboard aircraft carriers.

As a first step, he received a comprehensive audiologic evaluation, and substantial hearing loss was found. He learned that whenever tinnitus and hearing loss co-occur, it is important to address both conditions. The audiologic and tinnitus counseling he received prompted him to try amplification, a sound-based approach to help him with his tinnitus and improve his ability to communicate. In the video, he describes experiencing substantial relief from his tinnitus by using hearing aids. He also receives benefit from cognitive behavioral therapy and meditation to manage his reactions to his tinnitus. He also describes major improvements in his spousal relationship because of improved communication, which he had no idea had been the source of many "fights" that had created stress in the relationship. Sadly, Brian struggled with tinnitus and hearing loss for years without a proper health care referral.

### Clinical Practice Guidelines

From the foregoing, it should be clear that Service Members and Veterans often have a history of high noise exposure and PTSD, and therefore are likely to experience bothersome tinnitus and other auditory complaints that require appropriate health care. In addition to PTSD, there are many comorbid conditions that can exacerbate tinnitus symptom severity, which is why it is essential to perform a thorough medical evaluation on all patients with tinnitus. Unfortunately, many health care providers are either not familiar with clinical practice guidelines for tinnitus or choose not to follow their recommendations for other reasons.<sup>2</sup> Tunkel and colleagues<sup>23</sup> published a comprehensive clinical practice guideline for tinnitus and provide an evidence-based framework with suggested recommendations for tinnitus assessment and management, which are endorsed by the American Academy of Otolaryngology–Head and Neck Surgery Foundation (AAO-HNS), American Academy of Audiology, and American Speech-Language-Hearing Association.

The AAO-HNS clinical practice guideline for tinnitus strongly recommends all patients with tinnitus receive a targeted history and physical examination. These initial assessment procedures are essential to identify the tinnitus patients' primary complaint and inform the selection of appropriate follow-up testing, procedures, and referrals. When a patient reports tinnitus, in addition to questions to determine its type (ie, primary vs secondary), it is helpful

to determine if it is bothersome and if the patient experiences any triggers that exacerbate the condition. Sometimes patients are not aware of triggers that result in their tinnitus perception fluctuating. Therefore, asking specific follow-up questions (eg, “Does the loudness of your tinnitus change from time to time?” and “Does your tinnitus change when you move your jaw or clench your teeth?”) is helpful to screen for potential somatic components to the tinnitus and aid in the clinical decision-making process.

### **Somatosensory Tinnitus**

When patients’ report history of head injury, it is helpful to determine if the tinnitus perception is modulated by head and neck maneuvers and/or started after the injury. When attributes of the tinnitus percept, such as pitch or loudness, change immediately following certain head, neck, and/or jaw maneuvers, forceful muscle contractions, or eye movements, somatosensory tinnitus is suspected and suggests an interaction between the somatosensory and auditory systems.<sup>24–27</sup> Numerous studies have revealed that tinnitus is somatically modulated in many people<sup>26</sup> and could be attributed to cortical neuroplasticity initiated by subcortical changes occurring at the auditory brainstem level.<sup>25,28</sup>

When somatic manipulations directly influence the tinnitus perception, it suggests the possibility of an underlying musculoskeletal deficit of the head or neck and warrants taking a nontraditional approach to tinnitus management.<sup>29</sup> Tinnitus and musculoskeletal disabilities involving the head and neck (eg, cervical strain) are commonly reported by Veterans receiving care at VA facilities<sup>13</sup>; therefore, it is logical to postulate that many Veterans will have clinical features suggestive of somatosensory tinnitus, but the prevalence of somatosensory tinnitus in Veterans is unknown. Although limited research has been done investigating the effectiveness of various treatments for somatosensory tinnitus, what has been published related to physiotherapy is promising.<sup>29–32</sup>

### **Hyperacusis**

From a clinical perspective, all patients with tinnitus, regardless of the type of tinnitus, should be screened for hyperacusis. Estimates vary and are as high as 60% to 79% of patients with tinnitus have comorbid hyperacusis.<sup>33,34</sup> Hyperacusis is defined as an intolerance of sounds at low-to-moderate intensity levels that results in physical discomfort and can increase stress and anxiety.<sup>35</sup> When patients report any degree of decreased sound tolerance (DST), whether it be hyperacusis or another type of sound intolerance, it is paramount to address the issue clinically because it can negatively impact every aspect of daily functioning.<sup>36</sup>

Patients with severe DST often change their daily activities to avoid exposure to the “noise” of everyday life, which in turn leads to social isolation, worsening of symptoms, and reduced quality of life.<sup>37</sup> Clinical evidence suggests long-term avoidance and deprivation of sound counterintuitively results in increasing one’s sensitivity, rather than contributing to any degree of symptom reduction.<sup>38</sup> Many people who initially have a minimal degree of DST begin to use hearing protection in quiet environments with the intention of improving their condition, or preventing it from worsening. However, the act of depriving the ear and brain

from processing sounds at normal everyday levels ultimately increases the auditory system's responsiveness to sound and, in turn, increases the severity of their DST.

Often patients have a difficult time articulating their complaints and DST is defined differently among patients. Current clinical test procedures are not adequate to characterize the auditory-neurobehavioral phenomenon of DST and future research is needed to address these gaps in knowledge. When patients with tinnitus present with comorbid DST, asking for concrete examples of situations that evoke the response can assist in determining if the sound intolerance is related to the perceived loudness or some other aspect of the sound environment. Asking clarifying questions also assists in determining if the patient's complaint is a different problem entirely, such as difficulty understanding speech in noise.

### Ototoxic Medications

Also, critically important is to screen patients with tinnitus for use of ototoxic medications. Tinnitus is a common side effect of ototoxic medications and can occur in the absence of hearing loss with medications, such as anticonvulsants, diuretics, tricyclic antidepressants, vasodilators, organic solvents, and more.<sup>39</sup> When combined with an ototoxic agent, noise exposure results in more severe auditory damage than expected from either source independently.<sup>40</sup> This synergistic interaction between noise and ototoxic medications has been shown to result in more extensive damage to cochlear hair cells and supporting cells than would be caused by either one independently.<sup>41-43</sup> This combined effect is especially important to consider for patients who are prescribed the more potent ototoxic medications, such as certain aminoglycosides and antineoplastic agents that cause hearing loss and tinnitus at high rates.<sup>44,45</sup> Encouraging patients to use of hearing protection when exposed to noise is critical, but for these patients, it is recommended to take extra time to explain that they are far more vulnerable to the negative effects of being around moderate to high levels of noise.

When patients are taking highly ototoxic medications (eg, head and neck patients receiving adjuvant chemotherapy with a platinum-based drug), it is recommended to monitor these patients prospectively for the development of, or exacerbation of, tinnitus and self-perceived hearing difficulties.<sup>46</sup> These perceptual consequences are indicators of changes in the auditory status of the patient, and yet may go unnoticed because of the multitude of other medical concerns that need to be addressed when providing complex medical care. Additional considerations regarding patient-specific susceptibility for developing chemoradiotherapy-induced tinnitus and/or hearing loss include age, concomitant administration of ototoxic medications (nonsteroidal anti-inflammatory drugs, diuretics, aminoglycosides), and cumulative dose.<sup>47</sup> It has also been shown in animal models that cisplatin-induced ototoxicity can compound noise-induced auditory injury months following completion of the chemotherapeutic agent, suggesting a lasting effect in the form of increased susceptibility to damage.<sup>48</sup> This is consistent with recent results showing platinum compounds accumulate in the stria vascularis where they are not readily cleared.<sup>49</sup> When extrapolated to humans using evidence from human temporal bones, results in animal models of cisplatin ototoxicity indicate that the drug may reside indefinitely in the cochlea

consistent with development of late effects and long-term vulnerability to damage from noise.

When seeing patients who have a primary complaint of tinnitus, consider asking, “In the last 6 months, have you been exposed to loud noises where you had to shout to be heard?” Any affirmative responses would prompt the follow-up question: “Afterward, did you experience any ear pain, tinnitus, trouble understanding speech in noisy environments, or changes in your tinnitus or hearing?” Asking questions about exposure to noise in a general sense is a good opportunity to learn about your patient’s noise exposure history from a variety of sources (military, occupational, and recreational activities), and to have an honest conversation about hearing protection use (Box 1). There are many beneficial ways to help patients manage tinnitus-related problems, but until a cure is found, preventative measures remain the best option.

The most effective means to reduce the risk of noise-induced tinnitus is by using hearing protection. Earplugs and earmuffs come in a variety of styles; many patients and health care providers are not familiar with how to select appropriate hearing protection devices (HPDs) or verify they are being worn correctly to receive the most benefit. Providing instruction and making sure individuals receive the necessary training, including how to properly insert earplugs, are methods used in hearing conservation programs as strategies that have been shown to be successful in improving the use of HPDs effectively.<sup>50</sup>

Other factors to be aware of and discuss with patients include: (1) overall comfort when wearing HPDs, a variable that strongly influences how consistently HPDs are used; (2) personal health beliefs related to perceived risk (or lack of perceived risk); and (3) motivation to protect their hearing, including protection against developing auditory conditions, such as tinnitus and hyperacusis. The National Hearing Conservation Association has resources for interested health care professionals who want to learn more about best practice for promoting use of HPDs on their Web site: [www.hearingconversation.org](http://www.hearingconversation.org).

## SUMMARY

Because of repeated exposures to noise, military Service Members and Veterans are more likely to have tinnitus compared with civilians, and those who have comorbid mental health diagnoses are more likely to have increased tinnitus symptom severity.<sup>51</sup> Accumulating evidence suggests that tinnitus developed as a perceptual consequence of noise exposure may be an indicator of underlying auditory injury and maladaptive compensatory mechanisms within the central auditory pathways.<sup>52</sup> The prevailing view that “tinnitus is a symptom of hearing loss” is therefore misleading and does not tell the whole story.

It is critical for health care providers to know what can be done to help patients with tinnitus so that the phrase “nothing can be done” will cease being said. Not only is that statement inaccurate, hearing it reduces patients’ confidence in the ability of health care providers to help them and can lead patients to explore unhealthy options for short-term relief.

When patients present in the clinic with tinnitus, it is essential to determine what type of tinnitus the patient has and if it is bothersome or not. Being familiar with current clinical practice guidelines on tinnitus assessment and management not only promotes best practices, it aids clinicians in their decision-making process. Evaluating patients with tinnitus is nuanced and careful consideration should be paid to auditory and nonauditory comorbidities. Although there is no “cure,” there are many cost-effective management approaches available to help treatment-seeking patients with bothersome tinnitus. Table 1 is a miniguide that can be used as a reference for the major topics addressed in this article. The recommendations in Table 1 are not exhaustive; because of individual differences related to how tinnitus manifests and what is considered bothersome about it, tinnitus assessment and management should take a stepped-care approach, including consideration of the patient’s preferences along with a discussion of realistic goals and expectations, to best meet their needs.

There is a lot of misinformation and false claims about tinnitus on the Internet<sup>53,54</sup>; that, plus lack of guidance, can result in patients feeling overwhelmed and unsure of what to do. At a minimum, providing patients a handout with community resources, and/or a list of credible Web sites to obtain additional information (eg, American Tinnitus Association [[www.ata.org](http://www.ata.org)], Dangerous Decibels [<http://dangerousdecibels.org>], Noisy Planet [[www.noisyplanet.nidcd.nih.gov](http://www.noisyplanet.nidcd.nih.gov)]) helps patients be informed consumers. Ultimately, incorporating these elements into the care of patients with tinnitus will lead to improved health care outcomes and patient satisfaction.

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**Box 1****Suggested noise-exposure questions to include as part of assessment**

In the last 3 to 6 months, have you been exposed to loud noises where you had to shout to be heard?

*Yes, Sometimes, No*

If Yes or Sometimes:

After the event, did you experience any (circle all that apply):

*Ear pain, Tinnitus, Trouble understanding speech in noisy environments, Change in tinnitus, Change in hearing*

How often did or does your job cause you to be exposed to loud noises where you had to shout to be heard?

*Never, Rarely, Sometimes, Usually, Always*

If Sometimes-Always: Were you wearing hearing protection when this occurred?

*Never, Rarely, Sometimes, Usually, Always*

When you were exposed to loud noises, did you experience tinnitus?

*Yes, Sometimes, No*

How often did or do recreational activities cause you to be exposed to loud noises where you had to shout to be heard (eg, music concerts, power tools, motorcycles, hunting, target shooting)?

*Never, Rarely, Sometimes, Usually, Always*

If Sometimes-Always: Were you wearing hearing protection when this occurred?

*Never, Rarely, Sometimes, Usually, Always*

When you were exposed to loud noises, did you experience tinnitus?

*Yes, Sometimes, No*

**KEY POINTS**

- Military Service Members and Veterans often have a history of high noise exposure and experience tinnitus and other auditory complaints at higher rates compared with the general population.
- Tinnitus is a perceptual consequence of noise exposure and may be an early indicator of underlying auditory injury that can manifest before changes detected audiometrically.
- When combined with an ototoxic agent (eg, ionizing radiation, platinum-based chemotherapy, certain aminoglycoside antibiotics, loop diuretics, macrolides), noise exposure results in more severe auditory impairment than expected from either source independently, warranting the monitoring of patients receiving these therapies for development or exacerbation of tinnitus and hearing loss.

**Table 1**  
 Definitions of key concepts addressed in this article and recommendations for consideration

<b>Finding</b>	<b>Definition</b>	<b>Recommendation</b>
Primary tinnitus (with or without measurable hearing loss)*	Perception of sound in the absence of an external source that is idiopathic and may or may not be associated with sensorineural hearing loss*	Follow standard AAO-HNS Clinical Practice Guidelines and have patient be seen by an audiologist who is knowledgeable about tinnitus
Primary tinnitus + ototoxic medication	Ototoxic: agents that result in damaging auditory/vestibular end organs and possible damage to subcortical and cortical structures	Perform prospective ototoxicity monitoring and encourage use of hearing protection when exposed to noise
Somatosensory tinnitus	Changes in tinnitus percept (pitch, loudness, timbre) following head and neck maneuvers, forceful muscle contractions, eye movements, or jaw movements	Consider referrals to neurologist and physical therapist for additional work-up to rule out comorbid musculoskeletal head/neck deficit triggering or exacerbating the tinnitus
Hyperacusis	Intolerance of sounds at low-to-moderate intensity levels that results in physical discomfort (and may result in negative reactions)	Referral to audiologist who specializes in assessment and management of tinnitus and hyperacusis (modified test battery recommended so as not to exacerbate the condition); important to identify if tinnitus and/or hyperacusis is exacerbated by acoustic stimulation
History of noise exposure (occupational and/or recreational)	Exposure to intensity levels that can damage auditory function (eg, operating light or heavy machinery, manufacturing/factory work, lawn equipment, shooting range, attending sporting events, music concerts, mass transportation)	Review proper use of hearing protection devices and the different types available; discuss any barriers that exist to wearing hearing protection

\* *Definition from Tunkel DE, Bauer CA, Sun GH, et al. Clinical practice guidelines: Tinnitus. Otolaryngol Head Neck Surg 2014;151(2 Suppl):S1-40.*