The Relationship Between Blast-related Hearing Threshold Shift and Insomnia in U.S. Military Personnel

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ABSTRACT

Introduction:

Hearing loss and insomnia emerged as preeminent sources of morbidity among military service members and veterans who served in the recent Iraq and Afghanistan conflicts. Significant threshold shift (STS), an early indicator of hearing loss, has not been studied in relation to insomnia. This study's objective was to examine the co-occurrence of STS and insomnia among U.S. military personnel with blast-related injury.

Materials and Methods:

A total of 652 service members who were blast-injured during military operations in Iraq or Afghanistan between 2004 and 2012 were identified from the Blast-Related Auditory Injury Database. Pre- and post-injury audiometric data were used to ascertain new-onset STS, defined as 30 dB or greater increase for the sum of thresholds at 2,000, 3,000, and 4,000 Hz for either ear. Insomnia diagnosed within 2 years post-injury was abstracted from electronic medical records. Multivariable logistic regression analysis examined the relationship between STS and insomnia, while adjusting for age, year of injury, occupation, injury severity, tinnitus and concussion diagnosed in-theater, and PTSD.

Results:

A majority of the study sample was aged 18-25 years (79.9%) and sustained mild-to-moderate injuries (92.2%). STS was present in 21.1% of service members. Cumulative incidence of diagnosed insomnia was 22.3% and 11.1% for those with and without STS, respectively. After adjusting for covariates, those with STS had nearly 2-times higher odds of insomnia (odds ratio (OR) = 1.91, 95% CI = 1.12-3.24) compared with those without STS. In multivariable modeling, the strongest association was between PTSD and insomnia (OR = 5.57, 95% CI = 3.35-9.26). A secondary finding of note was that military personnel with STS had a significantly higher frequency of PTSD compared with those without STS (28.1% vs. 15.2%).

Conclusions:

Hearing threshold shift was associated with insomnia in military personnel with blast-related injury and could be used to identify service members at risk. Multidisciplinary care is needed to manage the co-occurrence of both conditions during the post-deployment rehabilitation phase. Future research should evaluate the specific mechanisms involved in this relationship and further explore the association between hearing threshold shift and PTSD.

INTRODUCTION

The battlefield is a high-risk environment for damage to the auditory system. Military personnel are regularly exposed to operational noise, including gunfire, explosions, and recurrent sounds associated with heavy machinery and vehicles.[1] Further, during the U.S. military conflicts in Iraq and Afghanistan, blast weaponry became the predominant mechanism of warfare employed by the enemy and, as a result, the majority of all combat wounds were from blasts.[2] The auditory effects of acute blast exposure are well-documented.[3–7] One recent military study found that, relative to a non-blast injury reference group, blast-related injuries conferred more than 2-times higher odds of hearing loss.[7] The confluence of risk factors, coupled with the protracted length of these military operations and multiple deployments to the combat zone, has increased the healthcare burden related to auditory issues.[8] Estimates place the annual cost of hearing loss disability among veterans in the billions.[9]

A separate but parallel issue of importance among military personnel is insomnia. Medical surveillance data showed

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that rates of insomnia increased significantly across all military branches through 2014[10] and has been described as "epidemic-like."[11] The operational environment presents multiple risk factors for impaired sleep.[12] The Millennium Cohort Study Team found that post-deployment sleep problems were significantly higher among those reporting combat exposure.[13] Disrupted sleep is also frequently comorbid with concussion and PTSD, two conditions closely linked to blast-related injury.[14,15] In addition, deployed personnel may experience irregular work schedules (e.g., shift work), which are predictive of later sleep problems.[16] Insomnia is associated with physical and mental health comorbidities and can be an occupational health hazard during military deployment as it negatively impacts performance and increases the risk of mishaps.[17–19]

A few studies have directly assessed the relationship between hearing loss and insomnia. A recent scoping review found two civilian studies that examined sleep quality among individuals with noise-related hearing impairment.[20,21] Test et al.[21] performed an occupational cross-sectional study and found that, although tinnitus was the main sleep-disrupting factor, hearing impairment was associated with 3-fold higher odds of sleep problems. Similarly, a slightly lower, but statistically significant association was later found by Lim and colleagues.[22] Other studies in civilian populations without documented noise exposure have yielded mixed findings.[23,24] A Scandinavian study found that, among elderly adults, those with hearing impairment reported more daytime sleepiness.[23] In contrast, Nakajima et al.[24] conducted a study within the Japanese general population and found that subclinical hearing loss was associated with longer sleep duration.

At present, there is not enough evidence to determine the association between hearing loss and insomnia with any granularity, particularly among military personnel with blast-related injury. Hearing threshold shift, or significant threshold shift (STS), is an early indicator of hearing loss[25] that has not been examined before in relation to insomnia, but could potentially be used to identify vulnerable service members. This study's objective was to examine the co-occurrence of hearing threshold shift and insomnia among U.S. military personnel with blast-related injury.

METHODS

Study Sample

The study sample was identified from the Blast-Related Auditory Injury Database (BRAID) and included 652 military personnel who were injured by a blast-related mechanism between the years 2004 and 2012 and had no pre-injury history of diagnosed insomnia or other sleep disorder. The BRAID is a repository of U.S. military personnel injured in Iraq or Afghanistan with pre- and post-injury audiometric data.[26] Individual audiometric records were linked to the Expeditionary Medical Encounter Database (EMED) for abstraction of injury-specific variables, the Defense Manpower Data Center for demographics, and the Military Health System Medical Data Repository (MDR) for medical diagnosis information.[27] More detailed information on the BRAID and EMED can be reviewed elsewhere.[26,27] This study was approved by the Institutional Review Board at Naval Health Research Center, San Diego, CA.

Measures

Significant Threshold Shift

The BRAID was linked to audiogram surveillance data from the Defense Occupational and Environmental Health Readiness System—Hearing Conservation program, which requires routine audiometric monitoring for personnel exposed to hazardous occupational noise.[28] Valid audiograms within 1 year before and after injury were used to ascertain STS. Audiograms contained pure-tone hearing thresholds measured in decibels (dB) for left and right ears at six test frequencies (500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz). Significant threshold shift was defined as per previous research as pre- to post-injury increase of 30 dB or greater for the sum of thresholds at 2,000, 3,000, and 4,000 Hz for either ear.[7]

Insomnia

Diagnoses of insomnia within 2 years post-injury were obtained from the MDR using ICD-9-CM codes 307.41, 307.42, 327.02, 327.09, or 780.52.[29] In the present study, insomnia was defined as the presence of at least one of these codes during the follow-up period. For exclusion purposes, pre-injury history of insomnia or other sleep disorder was indicated by the aforementioned codes plus the ICD-9-CM codes 327.20, 327.21, 327.26, 327.39, 327.51, 327.53, 347.0, 347.1, 780.50, 780.51, 780.53, 780.55, 780.57, 780.58, 780.59, 788.30, and 788.36.

Covariates

Electronic Defense Manpower Data Center records were used to determine age and occupation at time of injury. Age was calculated as the difference between birthdate and injury date and was categorized as 18-25 or 26 years and older. Occupation was categorized as infantry or non-infantry using the military occupational specialty code. Specific details regarding the injury incident were abstracted from the EMED clinical record. Injury severity was classified using the Injury Severity Score (ISS), a composite measure that accounts for injuries to different body regions, that was categorized as mild-to-moderate (ISS 1-8) or serious-severe (ISS $\geq$ 9). Presence of tinnitus and concussion diagnosed near the point of injury in-theater on the EMED clinical record were analyzed as per previous research.[6,30] Year of injury was categorized as 2004-2006 or 2007-2012 to attain equal-sized groups. A diagnosis of PTSD was identified by presence of at least one occurrence of the ICD-9-CM code 309.81 in the MDR at any time during the 2 years post-injury.

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TABLE I. Descriptive Characteristics of the Study Sample ($n = 652$)

Variable	Total, no. (%) ($n = 652$)	No STS, no. (%) ($n = 513$)	STS, no. (%) ($n = 139$)	P-value
Age at injury, years				.157
18-25	521 (79.9)	404 (78.8)	117 (84.2)	
26 and older	131 (20.1)	109 (21.2)	22 (15.8)	
Year of injury				.263
2004-2006	337 (51.7)	271 (52.8)	66 (47.5)	
2007-2012	315 (48.3)	242 (47.2)	73 (52.5)	
Infantry	470 (72.1)	363 (70.8)	107 (77.0)	.147
Injury Severity Score				.964
1-8	601 (92.2)	473 (92.2)	128 (92.1)	
9 or greater	51 (7.8)	40 (7.8)	11 (7.9)	
Tinnitus	191 (29.3)	146 (28.5)	45 (32.4)	.368
Concussion	381 (58.4)	301 (58.7)	80 (57.6)	.812
Post-traumatic stress disorder	117 (17.9)	78 (15.2)	39 (28.1)	.001

Abbreviation: STS, significant threshold shift.

Statistical Analysis

All data management and analyses were performed using SAS version 9.4 (Cary, NC). Descriptive characteristics were calculated for the study sample and compared by those with and without STS, and chi-square statistics were used to test for differences between groups. Cumulative incidence of insomnia and chi-square statistics were calculated individually by selected covariates. Multivariable logistic regression assessed the relationship between STS and insomnia, while adjusting for age, year of injury, occupation, ISS, tinnitus, concussion, and PTSD. Odds ratios (OR) and 95% CI were presented. The Hosmer-Lemeshow test was used to assess model fit with an alpha level of 0.10.

RESULTS

Characteristics of the study sample are shown in Table I. The cumulative incidence of STS was 21.3% (139 of 652). A majority of the study sample was aged 18-25 years (79.9%), injured during 2004-2006 (51.7%), in infantry occupations (72.1%), and sustained mild-to-moderate injuries (92.2%). Concussion and tinnitus were diagnosed in-theater in 58.4% and 29.3% of military personnel, respectively. Overall, 17.9% were diagnosed with PTSD within 2 years after injury, with a significantly higher frequency of PTSD in those with STS relative to those without STS (28.1% vs. 15.2%, $P = .001$).

Overall, the cumulative incidence of insomnia was 13.5% (88 of 652). Figure 1 presents incidence of insomnia by selected covariates. The largest difference in incidence of insomnia was in those with PTSD relative to those without PTSD (35.9% vs. 8.6%, $P < .001$). Incidence of insomnia was also significantly different between those with and without STS (22.3% vs. 11.1%, $P = .001$) and those with and without concussion (16.5% vs. 9.2%, $P = .007$). Insomnia incidence did not statistically differ by ISS or tinnitus ($P > .05$).

Univariate and multivariable logistic regression analyses are detailed in Table II. In multivariable analysis, STS was significantly associated with nearly 2-times higher odds of insomnia after adjusting for all covariates (OR = 1.91, 95% CI = 1.12-3.24). Post-traumatic stress disorder (OR = 5.57, 95% CI = 3.35-9.26) and injury years 2007-2012 (OR = 2.35, 95% CI = 1.38-4.02) were also associated with higher odds of insomnia. Concussion was statistically associated with insomnia in univariate, but not multivariable analysis. The Hosmer-Lemeshow test indicated the multivariable model was a good fit ($P > .10$).

DISCUSSION

The present study is the first to identify an association between hearing threshold shift and insomnia. With nearly two times higher odds of insomnia diagnosis among patients with STS, audiologists should be mindful of this potential comorbidity and refer individuals to sleep specialists when indicated. Likewise, blast-injured patients presenting with sleep complaints should be screened for auditory deficits. The crossover of these two health issues, STS and insomnia, further highlights the multifaceted nature of blast-related injuries and the need for providers to address the negative outcomes of blast exposure using an interprofessional collaborative approach.

There are multiple biological mechanisms that could explain the association between STS and insomnia, when considering that STS is an early indicator of hearing loss or impairment.[25] For example, anxiety has a strong relationship with insomnia.[31] Though we adjusted for PTSD, which is the most prevalent post-deployment anxiety disorder within the military, hearing impairment can also cause anxiety due to subsequent communication difficulties.[32] The hindered ability to communicate may lead to occupational challenges with colleagues or supervisors, and possibly even detriments to one's career.[33,34] For all sub-categories of anxiety, patients should receive a thorough assessment to rule out a diagnosis of insomnia. Another possible mechanism is that hearing impairment alters the cyclic structure of sleep or sleep

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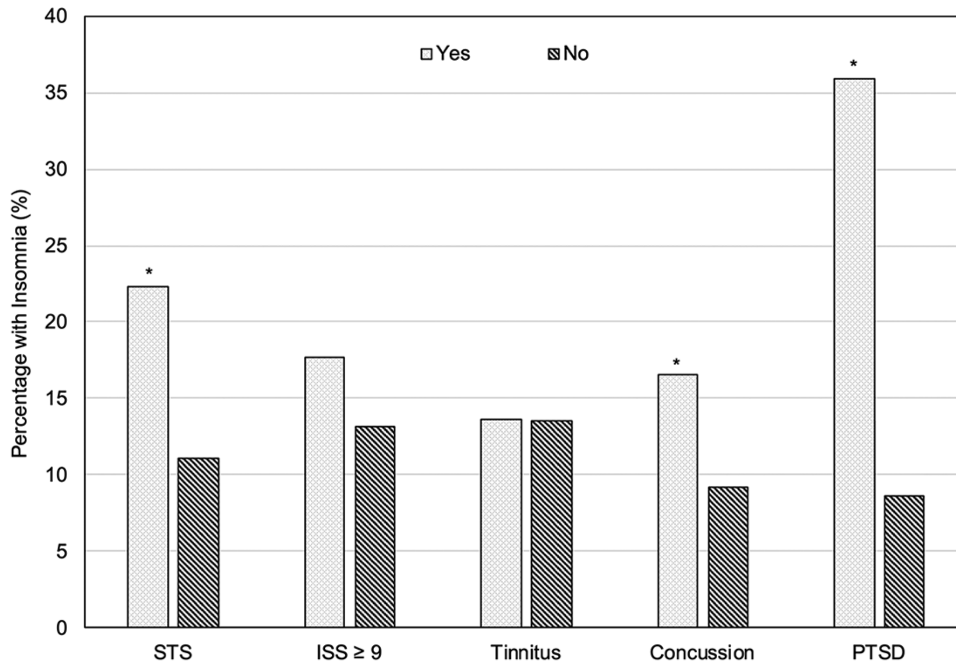

FIGURE 1. Cumulative incidence of insomnia presented by significant threshold shift (STS) status and selected covariates ($n = 652$).

TABLE II. Univariate and Multivariable Logistic Regression Models Examining Significant Threshold Shift (STS) and Insomnia ($n = 652$)

	Insomnia	
Variable	Univariate OR (95% CI)	Multivariable[a] OR (95% CI)
STS	2.30 (1.41-3.73)[b]	1.91 (1.12-3.24)[c]
Age, years		
18-25	Ref	Ref
26 and older	0.87 (0.49-1.55)	0.93 (0.49-1.74)
Year of injury		
2004-2006	Ref	Ref
2007-2012	2.60 (1.61-4.19)[b]	2.35 (1.38-4.02)[c]
Infantry	0.91 (0.56-1.49)	0.81 (0.47-1.41)
Injury severity score		
1-8	Ref	Ref
9 and greater	1.42 (0.66-3.02)	1.03 (0.44-2.43)
Tinnitus	1.01 (0.62-1.66)	0.72 (0.41-1.27)
Concussion	1.95 (1.19-3.19)[c]	1.68 (0.93-3.02)
Post-traumatic stress disorder	5.95 (3.67-9.66)[b]	5.57 (3.35-9.26)[b]

Abbreviation: OR, odds ratio.
[a]Multivariate model was a good fit as indicated by the Hosmer-Lemeshow test ($P > .10$).
[b]$P < .01$.
[c]$P < .05$.

architecture.[20] In a study of patients with Meniere's disease, an inner-ear condition characterized by progressive unilateral hearing loss and tinnitus, Nakayama and colleagues[35] found that patients relative to controls had decreased levels of sleep in stages II and III (i.e., transition to deep sleep) and a higher number of arousals. An experimental design that temporarily alters threshold sensitivity, while incorporating sleep monitoring, is necessary to explore this mechanism. Finally, tinnitus that persists after blast-related injury was not assessed in the present study but may play a role in the onset of insomnia. Test et al.[21] found that, while hearing impairment independently conferred 3-fold higher odds of poor sleep quality, tinnitus was a larger contributor with 12-times higher odds of poor sleep. Moreover, future research should incorporate longitudinal collection of data to determine which of these mechanisms is most plausible.

Clinical implications of the observed findings include efforts to streamline care for those with STS and insomnia. The military health system represents a vast network of specialty care clinics, and referrals are instrumental for obtaining patient evaluations from appropriate professionals. The emergence of blast-related injuries has prompted the use of integrated care models for conditions such as concussion, as treatment for these patients typically involves an interprofessional collaborative approach to manage co-occurring sequelae.[36] Because the concept of STS impacting sleep has not been previously studied, current bridges between audiology and sleep medicine professionals may not be firmly established. Providers in related disciplines should be educated on the potential overlap of STS and insomnia, incorporate screening instruments to triage patients accordingly, and work cooperatively to determine the best treatment approach for these issues. Due to the identified relationships between PTSD and both insomnia and hearing loss, multidisciplinary collaborative care should also include mental health professionals.[37]

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Notable secondary findings were present. Individuals injured in later years (i.e., 2007-2012 vs. 2004-2006) had higher odds of insomnia diagnosis. This aligns with a previous analysis from the Armed Forces Health Surveillance Branch, which found a steady increase in insomnia diagnoses over the course of the conflicts in Iraq and Afghanistan.[10] Another finding of interest was that military personnel with STS had a significantly higher frequency of PTSD than those without STS. Other recent research has identified a similar association,[37,38] and future studies are needed to determine whether STS could potentially act as an indicator for PTSD. Finally, the incidence of STS among blast-injured individuals (21.3%) was higher than that found in civilian workers (14%) and the general military population (11%),[39,40] which further highlights the burden of blast injury on the auditory system.

There are several limitations of the present study. Using ICD-9-CM codes to identify insomnia restricted the outcome to those presenting for care and may have excluded those with less severe symptoms, limited access to care, or who chose not to seek care. In addition, it was not possible to determine exact dates of STS and insomnia onset from the BRAID and MDR, respectively, and as such, temporality of STS in relation to insomnia could not be ascertained. It is possible that patients with STS experience varying levels of impairment or resolution of symptoms over time. Last, the measure of tinnitus used for adjustment purposes was obtained from in-theater medical records, which does not represent the occurrence of tinnitus at the time of insomnia diagnosis.

There are also strengths that warrant mention. Using pre- and post-injury audiometric data allowed for accurate ascertainment of STS and an increased likelihood that the blast-related injury was the initiating event. The EMED clinical record provided important injury-specific information for adjustment purposes, including the presence of tinnitus and concussion. Finally, the availability of pre-injury medical record information facilitated the exclusion of personnel with previous sleep disorders.

CONCLUSIONS

This study highlights the co-occurrence of hearing threshold shift and insomnia among military personnel with blast-related injury. Audiologists should collaborate with sleep medicine and mental health professionals to manage these patients, and future research needs to evaluate the specific mechanisms involved in this relationship. As blast injuries continue to predominate modern warfare, comorbidities such as STS and insomnia need to be identified and addressed to maximize force readiness and improve the overall well-being of active duty service members and veterans.

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CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest.

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