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Abstract

Background: Many service members deployed to the Afghanistan and Iraq theatre of operations are returning with multiple injuries, including traumatic brain injury (TBI) and sensory impairment. Studies of sensory impairment among patients with TBI have focused either on the auditory or visual modality. However, their co-prevalence, termed dual sensory impairment (DSI), is not well-documented. We examined self-reported rates of auditory and visual impairment in Afghanistan and Iraq war Veterans receiving TBI evaluations.

Methods: We obtained 36,919 TBI evaluations, which included self-report measures of auditory and visual impairment, performed in the Veterans Health Administration between October 2007 and June 2009. Military service and demographic information were gathered from the Department of Defense's Defense Management Data Center.

Results: 12,521 subjects who were judged to have deployment-related TBI and a comparison group of 9,106 subjects with no evidence of TBI were included in the final sample. The overall rates of self-reported sensory impairment were: 34.6% for DSI, 31.3% for auditory impairment only, 9.9% for visual impairment only, and 24.2% for no or only mild sensory impairment. Self-reported DSI rates were highest among those judged to have both a TBI and reported blast exposure. Regression analyses showed that auditory impairment was the strongest predictor of visual impairment, and vice versa, suggesting that these impairments may derive from a common source.

Conclusions: Veterans who screen positive for DSI should be systematically and comprehensively evaluated to determine the extent of impairment. Identifying dual sensory impairment would allow clinicians to collaborate and maximize rehabilitation.

Since 2001, more than 1.7 million troops have been deployed to Afghanistan or Iraq for Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF).(1) While most troops are returning from war with no physical injury, approximately 15-19% of returnees have been judged to have experienced a traumatic brain injury (TBI), termed a "signature injury" of these military operations.(2-4) The majority of TBIs are mild and symptoms usually resolve within hours or days, but for some they can persist for months or years after a traumatic event.(5)

With the increased use of bombs and other explosives, blast exposure has become a predominant cause of injury among OEF/OIF troops. Primary blast waves, which cause a sudden change in atmospheric pressure that impact the body's surface and internal structures, have been a leading cause of closed-head TBI.(6-8) Among 125 patient-events reported in OIF marines, 97% of the patients were injured due to improvised explosive devices (IEDs) or mines,(9) and in another study nearly 60% of blast-exposed OEF/OIF troops admitted to an army hospital were judged to have a TBI.(6)

Numerous injuries can result from blast or non-blast events (e.g., gunshot wounds, motor vehicle accidents, falls), but hearing and vision deficits may not be obvious in patients with TBI due to the lack of visible symptoms.(10, 11) However, sensory impairment is likely to impact patients' functional improvement(4) and activities of daily living by diminishing their ability to interact with their immediate environment and with others.

The ears are air-filled organs that are likely to sustain primary blast wave injury. Blast waves can over-pressurize the auditory pathway, resulting in damage to the tympanic membrane, middle ear, inner ear, or auditory cortex.(10, 12-15) Signs of auditory injury include hearing loss, tinnitus, and otalgia. Many studies have reported auditory disturbance in OEF/OIF troops,(2, 4, 11, 15-17) and in one 6-month study of OIF marines, auditory injury was the most frequently reported single injury type (23%).(9) Sixty-two percent of blast-exposed Veterans with TBI reported hearing loss (compared to 44% of patients with non-blast related TBI), with 58% diagnosed with pure sensorineural loss after undergoing audiometric evaluation.(15) A similar Veteran patient group with sensorineural hearing loss(18) reported hearing and communication impairment, despite audiometric results appearing in the normal range, suggesting potential central auditory processing deficits.(16, 19)

The eyes are also vulnerable to the primary and other effects of blast, especially when unprotected.(20) Trauma to the visual system can create a variety of symptoms stemming from damage that ranges from injuries of the eye globe to the visual cortex.(19, 21) Eye trauma in OEF/OIF is more frequent than in prior conflicts.(22) In one 8-month study of OIF troops who were deployed during an Iraqi insurgency, blast fragmentation was responsible for 82% of all ocular injuries, with IEDs accounting for the majority of these injuries.(23) A recent study documented vision impairments in 38% of OEF/OIF Veterans receiving inpatient care.(24) Vision loss was confirmed at a rate approximately 2.5 times higher in individuals exposed to blast versus not exposed to blast, and damage to the eye, orbit, and/or cranial nerves was highly associated with blast injury.(24) In a similar sample, self-reported visual impairment was one of the four of thirteen symptoms that differentiated patients who sustained TBI in combat versus noncombat.(25)

Given the prevalence of auditory and visual impairment in OEF/OIF Veterans, it is likely that a portion of this population experiences impairment in both sensory modalities, a condition termed dual sensory impairment (DSI).(4) In a study of 62 OEF/OIF returnees (mean age of 27 years) who had incurred blast-related TBI, professional evaluations determined that hearing impairment only, vision impairment only, and dual sensory impairment were present in 19%, 34%, and 32% of these patients, respectively.(4) After controlling for TBI severity, DSI was predictive of poorer functional improvement, signifying the importance of hearing and vision for rehabilitation outcomes. In an older non-TBI outpatient Veteran population, DSI was documented in 0% under the age of 65 years and in 20% of over the age of 85 years.(26) Together, these results suggested that DSI appearing in the current and younger Veteran cohort may indicate a premature deterioration in hearing and vision that may potentially have long-lasting effects.(4, 26)

DSI among patients with TBI is a challenge for clinicians providing rehabilitative care,(19) but its prevalence in OEF/OIF returnees beyond studies with modest sample sizes is currently unknown. Using large national Veterans Health Administration (VHA) and Department of Defense (DoD) databases, the goals of the present study were to determine the prevalence rates of self-reported auditory, visual, and dual sensory impairment, and to identify demographic and deployment-related factors associated with sensory impairment. This is the first study reporting results from these comprehensive data regarding auditory and visual impairment in OEF/OIF Veterans.

Methods

Design

We obtained 36,919 records that included demographic information and comprehensive TBI evaluations performed in VHA between October 2007 and June 2009. Military service information was gathered from the DoD's Defense Management Data Center.

Instruments

Comprehensive TBI Evaluation. Approximately 20% of OEF/OIF Veterans seeking VHA healthcare services screen positive for TBI and are then referred for a comprehensive second-level TBI examination.(27) During this comprehensive TBI evaluation, patients undergo a physical examination by a specialist and are asked a series of standardized questions about their deployment-related experiences regarding blast exposure and non-blast related injuries and pre- and post-deployment related trauma history. The protocol also includes the 22-item Neurobehavioral Symptom Inventory (NSI-22) which asks patients to self-report the extent to which any cognitive, affective, somatic, or sensory symptoms(28) have impacted them within the past 30 days. The evaluator then determines whether the patient history and clinical course is consistent with TB or other physical or behavioral conditions, and then develops a treatment plan.

Variables

Dependent variables. Auditory and visual variables were based on patients' self-reports of the extent to which "vision problems, blurring, trouble seeing" and "hearing difficulty" had affected them over the past 30 days on a five-point Likert-type scale ranging from 0 (none) to 4 (very severe). These data were treated in two ways: (a) as a quantitative scale or (b) as a dichotomous categorical variable, with "none" and "mild" difficulty combined.

Independent variables. The presence or absence of self-reported blast exposure and the clinical judgment of TBI (yes, no) were the stratifying variables, and demographic characteristics (age, gender) served as control variables.

Sample. Of the 36,919 comprehensive TBI evaluations performed for 36,426 unique patients included in the original dataset, test cases and duplicate TBI evaluations (n = 518), as well as cases involving inconsistent responses regarding blast exposure (*n* = 187) were eliminated to yield 36,214 cases from which to sample (Fig. 1). Of these, we focused on two groups, those who were judged to have deployment-related TBI (n = 12,521), and those who were not judged to have TBI (*n* = 9,106), for a study sample size of 21,627. We excluded patients who had reported sustaining a TBI at a time other than deployment to control for conditions under which a TBI may have been experienced (*n* = 6,840), and those who did not have complete data (*n* = 7,747). We included non-TBI patients as a comparison group that was likely exposed to similar conditions (*n* = 9,106). Table 1 summarizes the sample characteristics. The majority of TBIs identified through this VHA evaluation process are typically mild, but more serious forms of TBI may also be detected. For this study, we did not distinguish among TBI severity levels.

Data Analysis Strategy

Frequencies for categorical variables and means and standard deviations for quantitative variables were calculated. Chi-square tests were used to examine the association of levels of sensory impairment severity (categorical) with blast exposure and TBI, and Pearson product moment correlations were used to examine associations between auditory and visual impairment.

Separate multiple linear regression analyses were conducted to predict severity of self-reported auditory or visual disturbance using simultaneous solutions in a hierarchical manner. Predictor variables included demographic factors (age, gender), impairment of the other sensory modality, blast exposure, TBI, and the two- and three-way interactions among TBI status, blast exposure, and gender. Variables were entered in blocks, with the main effects entered first followed by the set of two-way interactions and then the three-way interaction. To determine the unique contribution of each set of predictor variables, each block was entered last relative to all other blocks of predictors. The change in variance associated with the last step represents the unique contribution of that set of predictors. This procedure was used to evaluate the unique contribution of the main effects prior to any interaction effects, the unique contribution of the two-way interactions over and above the main effects but prior to the three-way interaction, and the unique contribution of the three-way interaction over and above all other predictors.

Results

Rates of Auditory, Visual, and Dual Sensory Impairment

Statistical analyses were performed with the use of SPSS software, version 18.0. The average patient was a 31.3 year old male with 4.5 years of military service and 1.4 deployments. Among those who were judged to have deployment-related TBI (both blast exposed and non-blast exposed), self-reported sensory impairment rates were: 24.2% for none to mild sensory impairment, 9.9% for visual impairment only, 31.3% for auditory impairment only, and 34.6% for DSI.

The distributions of sensory impairment as a function of blast exposure and TBI are presented in Figure 2. Across all four groups, approximately 78% were exposed to blast, and 58% were evaluated as having TBI. The two groups with the most pronounced differences in distributions of sensory impairment were the "Positive TBI, blast exposure" group (Panel A) and the "Negative TBI, no blast exposure" group (Panel D). Visual comparisons of these panels show that nearly twice the proportion of patients in Panel D reported minor rates of sensory impairment and also higher rates of visual impairment, whereas auditory and dual sensory impairment were markedly higher among those in Panel A. Patients in the "Negative TBI, blast exposure" group (Panel C) reported higher rates of auditory impairment and lower rates of visual impairment compared to the "Positive TBI, no blast exposure" group (Panel B). Among all four conditions, rates of DSI ranged from approximately 1 in 3 (Panel A, top left) to approximately 1 in 5 (Panel D, bottom right).

More detailed information regarding severity of sensory impairment in patients with TBI (blast exposed and non-blast exposed) is depicted in Figure 3. For auditory impairment, there was a significant association between history of blast exposure and severity of sensory complaint, $\chi^2(3) = 198.20$, $p < .0001$; *Cramer's V* = .13. Specifically, a higher percentage of positive TBI, blast-exposed patients reported moderate to very severe levels of impairment as compared to positive TBI, non-blast exposed patients. An association with blast exposure was also observed regarding visual impairment, $\chi^2(3) = 16.96$, $p = .001$, but the effect was weaker (*Cramer's V* = .04) and in the opposite direction, with more patients in the positive TBI, non-blast group reporting very severe visual impairment.

Those who were exposed to blast reported higher rates of moderate to very severe auditory impairment compared to visual impairment. In the non-blast conditions, a similar trend is observed, although the rates of auditory and visual impairment were more comparable to one another.

Contributors to sensory impairment

Auditory and visual impairment were significantly correlated, $r(21625) = .33$, $p < .0001$, and therefore auditory impairment was included as a control variable in the regression model predicting visual impairment, and vice versa . The linear multiple regression model predicting auditory impairment was significant, $F(9, 21603) = 370.05$, $p < .0001$, accounting for 13.3% of the variance in impairment (Table 2). The block of demographic and sensory impairment predictors accounted for the most variance (10.8%). Visual impairment was the largest predictor of auditory impairment, accounting for 9.2% of the variance, followed by gender (0.5%) and age (0.1%). Deployment-related events were the second strongest block of predictors (2.5%), with both blast exposure (1.3%) and TBI (0.8%) contributing significantly. The block of two-way interactions was not significant overall (accounting for <0.001% of the variance), although the TBI X Blast interaction accounted for a very small (0.02%) but significant amount of variance in auditory impairment. We further explored the means of the TBI X Blast interaction and found that patients who were exposed to blast and were judged to have had a TBI reported the highest levels of auditory impairment (M = 2.0, SD = 1.2), whereas those with no blast exposure or TBI had the lowest levels of auditory impairment (M = 1.3, SD = 1.2). The three-way TBI X Blast X Gender interaction did not contribute any significant variance (<0.001%).

The linear multiple regression model for visual impairment was also significant, $F(9, 21603) = 342.40$, $p < .0001$. The block of demographic and sensory impairment variables accounted for the largest percent of variance in visual impairment (11.7%), with auditory impairment accounting for the most within this block (9.3%), followed by age (1.1%) and gender (0.5%). The deployment-related events block accounted for 0.008% of the total variance, with TBI significantly contributing the most variance (0.69%), followed by blast exposure (0.14%). The two-way and three-way interactions were not significant predictors of visual impairment.

Discussion

The goals of this study were to document the prevalence of self-reported DSI and to identify contributing factors related to self-reported auditory and visual impairment in OEF/OIF service members who underwent a VA comprehensive TBI evaluation. A main finding was that the co-existence of sensory impairment was common. Depending on exposure to blast and TBI status, rates of visual impairment ranged from 8.5% to 15.7%; auditory impairment from 21.0% to 33.0%; and DSI from 22.7% to 35.4%.

The regression models showed that sensory impairment in one modality (i.e. auditory or visual) was the largest predictor for sensory impairment in the other modality. This finding suggests that either these impairments have a single source (e.g., brain trauma with associated dysfunction) or that damage to the two systems stems from a common source (e.g., blast wave, shrapnel). There is no evidence to suggest that impairment to one system leads to impairment in the other.

Blast exposure and TBI were significant but small contributors to sensory impairment, with blast-exposure accounting for more variance in auditory impairment than visual impairment. The interaction of TBI and Blast showed that those who experienced blast exposure and were evaluated as having TBI reported higher rates of auditory impairment than any other condition; this result was consistent with other studies reporting the deleterious effects of blast-related TBI on hearing.(4, 15, 16, 19)

A striking finding was that 1 in 5 patients who reported no exposure to blast and were not judged to have a TBI still self-reported moderate to very severe DSI. While it is impossible to know about all pre-military, general military, and battlefield conditions, several situations may help explain these findings. We note that auditory impairment was more prevalent than visual impairment. Some service members have complained that wearing earplugs prevents them from being keenly attuned to their environment.(29) Exposure to noise from the general military environment and weaponry,(15, 19) coupled with the tendency of some service members to forgo ear protection,(9) may create an extra vulnerability to auditory system damage. Regarding vision, one study(9) reported eye problems occurring in only 0.5% of troops, citing ballistic eye gear as a likely protectant. Nearly 100% of these marines wore ballistic eye protection, which typically sustained shrapnel and debris damage.(9) However, polycarbonate ballistic eyewear cannot protect against all ocular trauma, such as targeted hits from bullets or projectiles that impact the eye via other parts of the face.(23) As was the case with earplugs, some combat troops have viewed protective eye armor as intrusive,(21) which could decrease its rate of utilization.

Limitations

We note three primary limitations of this study. First, degree of sensory impairment was based on patient self-report, which is subjective and potentially inaccurate. Second, because the types of hearing and vision problems experienced by the patients were not specified in the databases, the nature of self-reported sensory impairment was not clear. To be fair, the TBI evaluation process is meant to evaluate whether the patient experienced a TBI or is experiencing other conditions that may require further assessment. Information obtained during the TBI evaluation provides a good gateway for additional discussion about patient complaints and an opportunity to refer for specialty care. Finally, we caution that this sample may not be characteristic of OEF/OIF returnees as a whole, but rather may only be representative of OEF/OIF returnees who (a) used VA health care services, (b) were referred for additional TBI evaluation after a positive preliminary TBI screen, and (c) came to the clinic and completed the comprehensive evaluation. Therefore, compared to the general OEF/OIF Veteran population, the rates of visual and auditory impairment reported here may be slightly inflated by the fact that these patients referred for a TBI evaluation had an increased likelihood of having experienced a TBI.

Implications

Vision and hearing are two key modalities through which people interact with and make sense of their environment. Patients with impairment in one sensory modality may be able to compensate by relying on a different sensory modality.(30, 31) Without vision(32) or hearing therapies,(16, 19) untreated impairment can challenge patients' abilities to read, drive, communicate, interact, and participate in some work environments. Rehabilitation efforts can be compromised further if the patient has TBI. (33)

The prevalence of single and dual sensory impairment in our sample suggests that patients undergoing a comprehensive TBI evaluation should also be screened systematically for sensory impairment beyond the NSI-22. Hearing and vision examinations could identify existing sensory deficits and may also lead to collaborative efforts among clinicians to diagnose, or rule out, any other conditions, such as neuropsychological dysfunction.(19) In this relatively young cohort of Veterans that could require decades of care, a comprehensive, multidisciplinary evaluation may provide early detection of impairment that sets the patient on the appropriate rehabilitation course.

Conclusions

In the largest study of its kind to date, we found that self-reported auditory and visual impairment were prevalent among OEF/OIF Veterans receiving a VA comprehensive TBI evaluation, and that DSI ranged from 1 in 3 (positive TBI, blast exposed) to 1 in 5 (negative TBI, non-blast exposed). These results suggest that complete audiologic and visual examinations should be included in standard comprehensive TBI evaluations.

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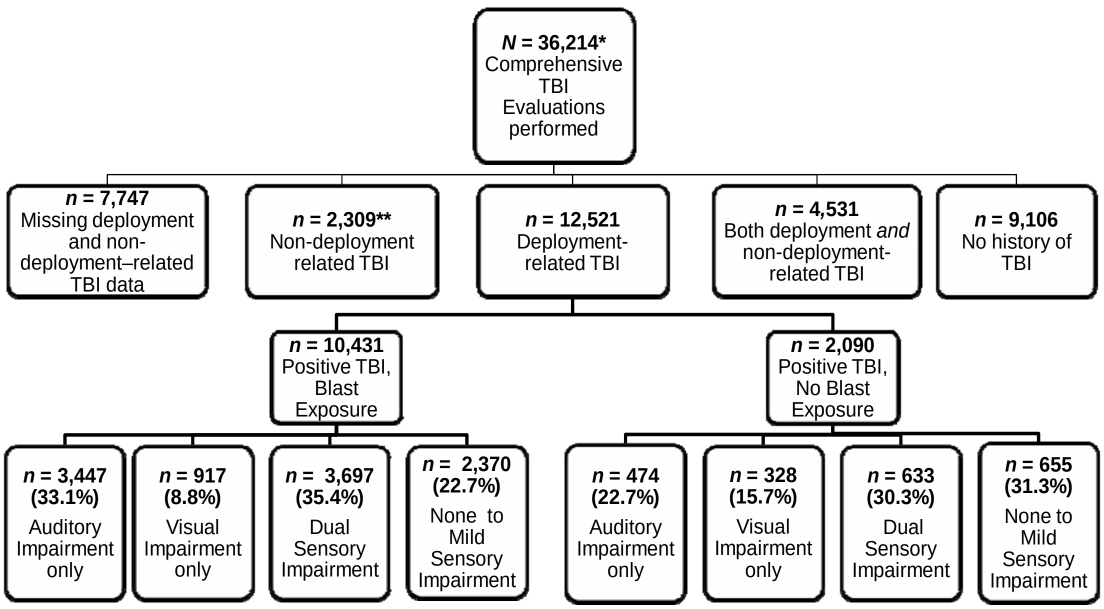
Figure 1. Prevalence of self-reported sensory impairment in OEF/OIF returnees who received a comprehensive TBI Evaluation.



Note: Impairments were self-reported and not yet verified by professional audiologic or visual testing.

**Excludes 518 test cases or repeat TBI evaluations and 187 cases with inconsistent blast responses (85 from deployment-related TBI only, and 102 from No history of TBI groups)*

***Non-deployment related TBI documented in notes, but no overall history of TBI indicated.*

Figure 2. Percentages of sensory impairment as a function of self-reported blast exposure and evaluation of TBI.

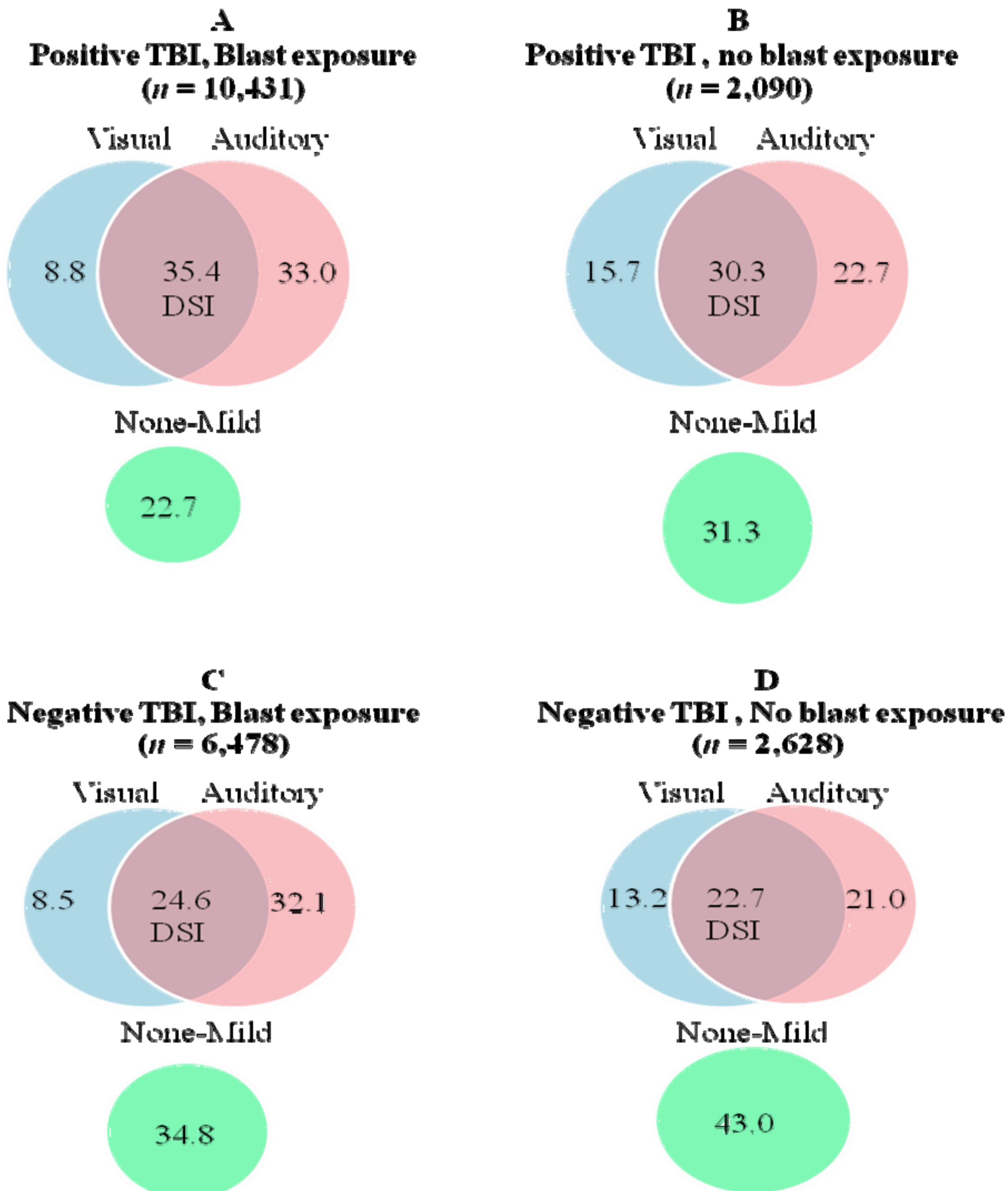
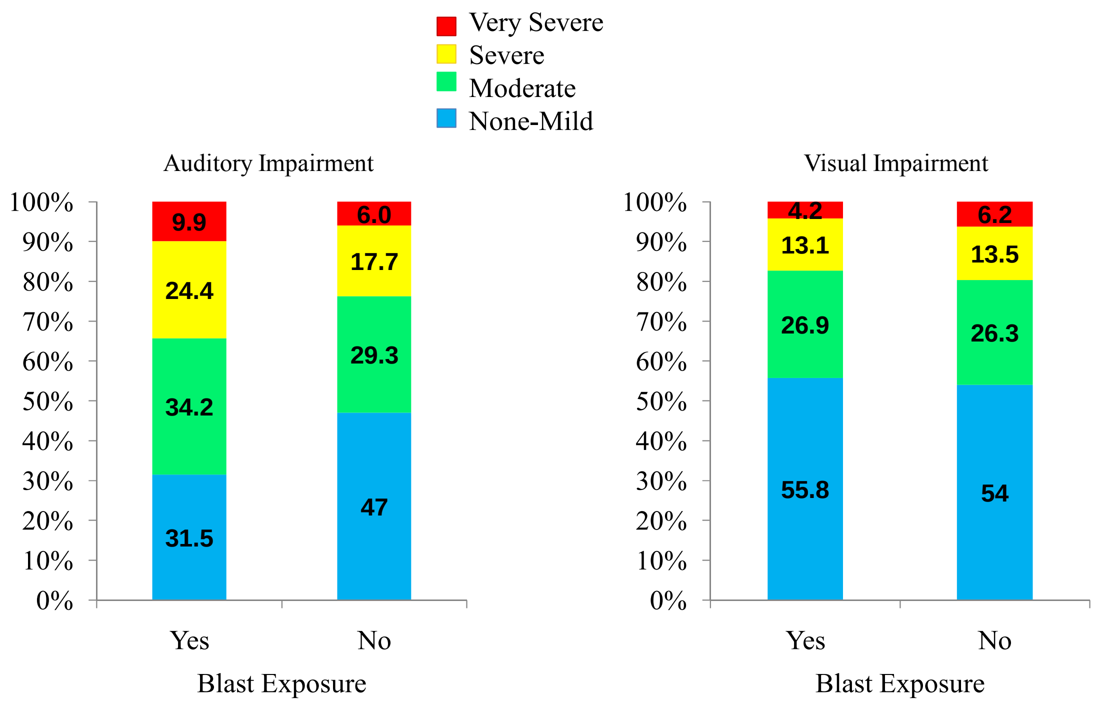


Figure 3. Proportions of patients judged to have TBI by level of sensory impairment and blast exposure (*N* = 12,521).



Note. Blast-exposed, positive TBI (*n* = 10,431); Non-blast exposed, positive TBI (*n* = 2,090)

Table 1. Demographic and event-related factors (*N* = 21,627)	
Factors	***n* (%)**
Gender	
Female	1,319 (6.1)
Male	20,306 (93.9)
Age	*M* = 31.3, *SD* = 8.6 Range: 18-65 years
Married/partnered	10,852 (50.3)
Pre-military education	
High school or less	12,032 (56.0)
Some college	7,909 (36.8)
College degree or post-baccalaureate	1,541 (7.1)
Current employment	
Working part-time/full-time	11,423 (55.0)
Student	2,233 (10.8)
Volunteer	49 (0.2)
Homemaker	126 (0.6)
Unemployed	6,930 (33.4)
Branch of Service	
Army	15,856 (73.3)
Marines	3,763 (17.4)
Air Force, Navy, Other	1,766 (8.1)
Years of service	Median = 4.0 Range: 0-36 years
Number of deployments	Median= 1.0 Range: 1-19*
Deployment-related TBI (Yes)	12,521 (57.9)
Blast exposure (Yes)	16,909 (78.2) *M* = 3.0, *SD* = 1.7

*The number of deployments can be high due to the methodology used to count the deployments. For example, each flight mission undertaken can be considered as a deployment resulting in a high number of deployments for Air Force personnel.

Table 2. Multiple Linear Regression Results Predicting Auditory and Visual Impairment				
	Auditory Impairment		Visual Impairment	
	Domain Unique Variance	Variable Unique Variance	Domain Unique Variance	Variable Unique Variance
Demographic and Sensory Impairment Characteristics	10.8%		11.7%	
Age		0.1%**		1.1%**
Gender		0.5%**		0.5%**
Auditory Impairment		---		9.3%**
Visual Impairment		9.2%**		---
Deployment-related Event	2.5%		0.008%	
TBI		0.8%**		0.7%**
Blast		1.3%**		0.1%**
Two-way Interactions	<0.001%		<0.001%	
TBI X Blast		0.02%*		<0.001%
TBI X Gender		0.02%*		<0.001%
Blast X Gender		<0.001%		<0.001%
Three-way Interaction	<0.001%		<0.001%	
TBI X Blast X Gender		<0.001%		0.02%
Total Domain Variance before 2-way Interactions	13.3%		12.4%	
Total Domain Variance before 3-way Interaction	13.3%		12.4%	
Total Domain Variance including all Interactions	13.3%		12.4%	

Note: Unique variance of each specific demographic, deployment-related event, and interaction is presented. Variable with asterisks indicate statistically significant predictors of sensory impairment.

*$p \leq 0.05$, **$p \leq 0.001$.