



U.S. Department of Veterans Affairs

Public Access Author manuscript

Brain Inj. Author manuscript; available in PMC 2019 March 14.

Published in final edited form as:

Brain Inj. 2017 ; 31(9): 1183–1187. doi:10.1080/02699052.2016.1274781.

Hearing complaints among veterans following traumatic brain injury

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Abstract

It has been shown that there is an increased risk for impaired auditory function following traumatic brain injury (TBI) in Veterans. Evidence is strongest in the area of self-report, but behavioural and electro-physiological data have been obtained that are consistent with these complaints. Peripheral and central dysfunction have both been observed. Historically, studies have focused on penetrating head injuries where central injury is more easily documented than in mild closed head injuries, but several recent reports have expanded the literature to include closed head injuries as well. The lack of imaging technology that can identify which closed head injuries are likely to impact auditory function is a significant barrier to accurate diagnosis and rehabilitation. Current behavioural and electrophysiological measures are effective in substantiating the auditory complaints of these patients but leave many questions unanswered. One significant limitation of current approaches is the lack of clear data regarding the potential influence of those mental health comorbidities that are very likely to be present in the Veteran population. In the area of rehabilitation, there are indications that hearing aids and other assistive listening devices may provide benefit, as can auditory training programmes, yet more research needs to be done.

Keywords

Hearing; TBI; auditory; Veteran; auditory processing

Background

The most detailed information available on the relationship between brain injury and auditory function comes from the Vietnam Head Injury Study (VHIS). Field neurosurgeons initially completed registry forms identifying those who suffered Traumatic Brain Injuries

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(TBI) during the Vietnam conflict. In four subsequent phases, the VHIS conducted both chart reviews and prospective evaluations of those registered. During Phase Two, conducted during the 1980s, 520 of the original 2,000 registrants were invited to be evaluated at Walter Reed Army Medical Center, where audiological assessments were conducted in conjunction with many other types of assessments including computed tomographic imaging. A control group of 85 uninjured Veterans of the Vietnam conflict was tested concurrently. Audiological evaluations included standard clinical tests of peripheral hearing function including pure-tone sensitivity, speech audiometry and immittance measures as well as a battery of behavioural and electrophysiological measures of central auditory processing. Many of these measures are presented in Table I. Due to the relatively large number of study participants and the broad scope of testing, these data [1–6] provide the clearest picture available, then or now, of how injuries to specific brain areas can be related to auditory processing difficulties. These studies provided strong evidence that damage to brain areas thought to be involved in auditory processing, such as the temporal lobe and corpus callosum, can result in dysfunction observable on clinical tests. They also showed that these tests are capable of dissociating peripheral and central system dysfunction. The following is a review of the current state of knowledge regarding the relationship between TBI and auditory dysfunction, compiled from data beginning with the VHIS through the most current research from modern warfighters and civilians.

Recent evidence of auditory dysfunction following TBI

One of the most common causes of TBI in current and recent military Service Members involves exposure to high-intensity explosive discharges [7]. While the majority of reports regarding TBIs sustained in military conflicts prior to the year 2001 involved focal penetrating injuries such as those reported in the VHIS, TBIs from blast exposure are now garnering the majority of the attention from the research community and the media. This shift reflects both the improved armour that makes penetrating wounds less likely and the increased awareness of the damage that can be caused by closed head wounds. Blast exposure is now understood to have the potential to result in widespread brain damage caused by the compressing and stretching of tissues as the shock front of the blast wave impacts the head [8]. Such diffuse injuries are then often compounded by secondary and tertiary blast injuries from when the head is impacted by flying debris or abrupt contact with the ground or other solid structures. The majority of blast-related TBIs are categorized as mild (mTBI), a classification that is based upon the symptoms at the time of injury and a lack of abnormal findings on common clinical neural imaging scans. However, even such ‘mild’ TBIs can have lasting impacts, particularly when the injured person is subjected to multiple head injuries as is frequently the case among recent Service Members. Further, such patients frequently suffer from additional health concerns such as chronic pain, sleep disorders, mental health issues and/or persistent cognitive symptoms. Such comorbidities may sometimes obscure or confound validation and treatment of auditory dysfunction. Hence, it is critical that evaluations following TBI include thorough sensory assessments to ensure that impairments are not missed.

Peripheral injuries from blast exposure such as tympanic membrane rupture and ossicular chain discontinuity are common, but often resolve within a few months of injury either

spontaneously or in response to surgical intervention [9]. Permanent sensorineural hearing loss in this population is normally treated with commonplace methods including hearing aids and assistive listening devices. Routine clinical audiometric assessments are normally adequate to evaluate and prescribe treatment for peripheral auditory concerns such as these. However, evaluating the effects of TBI on central auditory processing requires additional non-standard assessment techniques which often begin with thorough case histories and self-report of auditory function provided by the affected patient.

Self-report

Increasing numbers of head-injured Service Members and Veterans have recently sought audiology services for hearing issues only to learn that they have essentially 'normal' hearing thresholds, as determined by pure-tone audiometric assessment [10]. The most common complaints driving such patients to seek care include increased difficulty understanding speech in the presence of background noise and difficulty following rapidly spoken or long-running speech, as well as problems understanding speech over the telephone. Self-report indices of auditory function in Veterans with previous head injury often reveal a striking similarity to the reports of older presbycusis listeners [10]. In fact, a recent study revealed that even after several years of recovery following injury, 60% of a sample of Veterans with previous blast exposure and normal or near-normal pure-tone hearing thresholds reported moderate to severe hearing handicap which significantly affected their daily lives [11]. Similar results were recently reported for a group of patients with non-military mTBI [12]. Such data clearly indicate that patients with previous head injury who complain of auditory difficulties should always be evaluated for possible auditory processing disorders, even when the injury event occurred several years prior to the evaluation.

Behavioural measures

Behavioural test batteries for auditory processing disorders (APD), of which many are dependent on normal or near-normal pure-tone thresholds in order to accurately interpret the test results, generally assess functions including binaural integration, speech understanding in noise, recognition of filtered or degraded speech, and temporal processing ability. Most studies indicate that head injury can yield a wide scope of potential dysfunction across individuals. For this reason, it is not possible to capture all potential dysfunction in this population without employing a diverse test battery. The results of the VHIS, which assessed Veterans who had sustained focal cortical injuries, revealed important insights into correlations (or lack thereof) between performance on behavioural test measures and damage to specific cortical and sub-cortical areas. For example, a monaurally presented test measuring comprehension of 60% time-compressed monosyllabic words revealed that damage to the right or left auditory cortex had little bearing on the performance for either ear [1]. Of Veterans with previous damage to the left temporal lobe, 27% performed abnormally on this test with no signs of contralateral ear effects, and the percentage of abnormal performance was 22% for those with damage to the right temporal lobe. For dichotic listening tests including the Staggered Spondaic Words test (SSW), Dichotic Digits test (DDT) and the Dichotic Consonant Vowels test, on the other hand, damage in the right temporal cortex was associated with a contralateral ear deficit while damage in the left

temporal cortex often was associated with bilaterally degraded performance. The lack of contralateral ear effects in patients with damage to the left auditory cortex is somewhat surprising as most studies on non-Veteran populations with focal intracranial lesions usually indicate a strong laterality effect regardless of the side of lesion [13].

Results of four key studies in which the site of lesion was able to be verified and abnormal performance was observed on one or more auditory tests are summarized in Table I. Overall, the data in Table I illustrate that studies of penetrating wounds in Veterans and in non-Veteran head-injured populations both show deficits in dichotic listening tasks even when tested many years after the injury. The same pattern of abnormal performance has been found for those who have been blast exposed. In addition, the pattern for those tested within 1 year of exposure was the same as for those measured up to 10 years post exposure [10,11,14]. Based upon information from populations with more focal lesions, these patterns of results suggest that blast exposure has the potential to damage auditory brainstem and/or cerebrum as well as non-auditory-specific structures such as the corpus callosum and frontal cortex.

In addition to dichotic listening deficits, Table I contains an example of a study illustrating the finding that temporal processing deficits are also common among patients with head injury [15]. Gallun et al. [11,14] found that blast-exposed individuals can also exhibit significant levels of abnormal performance on temporal tests. Performance was abnormal on the Gaps-in-Noise (GIN) test, which assesses temporal acuity, and on the Frequency Patterns Test (FPT), which measures recognition and recall of temporal pattern changes. Both of these tests have been shown to be sensitive to auditory processing deficits following localized brain injury [15,16]. The finding that blast exposure impacts both temporal processing and dichotic speech understanding is consistent with the emerging literature on central auditory dysfunction following mild TBI (mTBI), as well as Refs. [17–21].

Electrophysiology

Electrophysiological measures have been widely used to assess the response of the auditory system following TBI. While behavioural tests of auditory processing in patients with previous head injury are often hampered by cognitive deficits including language, attention, and memory, auditory-evoked potentials (AEPs) can help to disambiguate cognitive dysfunction from auditory dysfunction, while also providing a powerful means of non-invasively establishing the site of lesion. Furthermore, AEPs often can be measured in patients who are unable to respond behaviourally, such as in cases of severe brain injury.

Auditory brainstem responses (ABRs) are rarely found to be abnormal in cases of mild or moderate TBI, regardless of whether they are obtained during acute or chronic phases of injury [8,17]. Abnormal ABR findings are more prevalent in cases of severe TBI, in which they often indicate a poor future outcome for patients [16]. The most common abnormal ABR findings among patients with previous TBI include increased Wave V absolute latency, prolonged I–V and/or III–V interpeak latency, or absence of Wave V. Middle-latency responses (MLR), which reflect the response of the upper brainstem and thalamocortical auditory circuits, are the least well studied of all AEP measures in the head-injured

population in part due to significant within- and between-subject variability. Available studies suggest that the amplitude of MLR waves are negatively correlated with severity of TBI, and that the presence of discernible MLR waveform morphology may be indicative of awakening from coma in cases of severe TBI [24,25].

Late-latency responses (LLR) reflect the response of cortical regions to auditory stimuli. Findings on the effects of head injury on the early components of the LLR (N1 and P2) have been mixed, particularly in cases of mTBI. Some studies report significant increases in the latencies and decrements in the amplitudes of these components while others report no effects [25]. Overall, it seems that the more severe the injury, the greater the risk that a patient will display abnormal early cortical potentials. The electrophysiological response with the most reliable relationship with head injury is the P300, which is a vertex-positive potential that occurs roughly 300 ms after the onset of a stimulus that deviates from the set of expected stimuli. The P300 is generated by multiple sites in the brain, including frontal and parietal areas outside the auditory pathway. The latency and amplitude of the P300 measure in response to the deviant stimulus appear to be well correlated with the severity of the TBI, with increasing latency and decreasing amplitude associated with increasing levels of injury [26]. The P300 waveform is usually found to be abnormal in patients with severe TBI, and is often (though not always) found to be diminished in cases of mTBI [16]. Whether or not mTBI results in aberrant P300 responses likely depends upon a number of factors including the type of head injury (e.g. blunt-force trauma, blast exposure) as well as the number of previous neurological insults and age of the patient. Though the majority of P300 studies on patients with mTBI have focused on civilian populations, two recent reports of changes in LLR in response to blast injury [14,17] found results similar to that observed with more severe TBI, in which the injured patients had lower amplitude LLRs that occurred later in time compared to age- and hearing-matched controls.

Overall, the majority of available studies suggest that cases of severe TBI sometimes result in abnormal early AEP responses and almost always result in abnormal LLR, while cases of mTBI rarely result in abnormalities at the brainstem level but are often reflected in LLR AEPs such as the P300. This suggests that early pathways of the auditory system may be less vulnerable to damage in mTBI cases than are the cortical auditory pathways that have strong connections to other cortical areas. Because the majority of AEP studies have focused on civilian populations, additional research is needed in order to determine whether the AEP results from such studies accurately reflect the auditory deficits that result from the types of head injuries common in warfighters (e.g. blast exposure).

Additional considerations

It is an ongoing challenge to provide evidence linking brain injury with behavioural performance for Veterans with auditory complaints and a history of blast exposure and/or mTBI. There is no clear epidemiological evidence regarding the prevalence of auditory dysfunction following mTBI, although the literature reviewed briefly above certainly suggests that such deficits are commonly observed both in Veterans and civilians following mTBI. More concerning, however, is the lack of clear diagnostic tools in the imaging domain that would allow such deficits to be tied to specific brain injury, either in particular

auditory areas, or diffusely throughout the auditory pathway. The most promising work is in the area of white matter integrity, which has recently been shown to be impaired in Veterans with mTBI [27,28], and resting state functional magnetic resonance imaging [29,30], although neither of these very promising techniques is yet in common usage as a clinical tool and neither have yet been applied to auditory dysfunction. Until such tools are developed and validated in a form usable by the clinician, it will be difficult to distinguish brain injury from the other factors that could result in auditory deficits for this population.

Some of the other factors that have been proposed include emotional issues such as post-concussion syndrome and posttraumatic stress disorder [20], as well as interactions with various medications, sleep deprivation associated with emotional difficulties, and general cognitive deficits that can affect performance on auditory measures. Future work will need to focus both on dissociating these factors on a group level and on developing measures that can be used to allow the clinician to better assess these interacting effects at the level of the individual patient. Blast exposure and TBI lead to diverse behavioural effects, and there is currently little evidence that can be used to associate specific auditory dysfunction with damage to discrete brain areas in those cases for which the brain images appear to be normal given the current technology. Consequently, it is essential that clinical research studies focus on the development and validation of a battery of rapid tests that can be used to identify patient-specific dysfunction in the auditory domain. Related to this is the need for a team approach to treatment, in which representatives from all of the disciplines relevant to diagnosing and treating brain injury are participating and communicating in the treatment of the patient.

Finally, it is important to recognize the fundamental difficulty associated with the retrospective nature of the analyses that have been conducted, which is that there are seldom clear indications of the abilities of the patients before injury. This problem, which faces the clinician as well, makes it very difficult to know whether abnormal performance is a result of injury or was already present. The military is increasing the level of pre-deployment testing on many relevant tests, but none are of the type needed to provide clear baselines for auditory function. The most common way of addressing this is to use control groups matched in age and peripheral hearing abilities to the patient groups, but this method has drawbacks as well, in particular, we often find that these groups often produce somewhat variable data. Consequently, the analysis of group differences is hindered and the researcher or clinician is forced to rely upon patterns of abnormal performance across multiple tests, which runs the risk of failing to identify deficits that are confined to a very specific auditory ability.

Rehabilitation

Clinicians have grappled with the question of what rehabilitation would help Veterans who experience auditory difficulties despite having normal or near-normal pure-tone hearing thresholds. This is particularly challenging in the light of the diagnostic challenges listed above, as well as the potential comorbid conditions. An optimal solution would be auditory training programmes to improve detection, discrimination and recall of auditory information, thus helping Veterans return to a more 'normal' level of auditory function without the use of

assistive devices. However, while brain training programmes show promise among patients who complete the training regimen [31], compliance is low, especially in this population which often includes working adults with numerous responsibilities. Available training programmes are often lengthy and monotonous and thus difficult for young and middle-aged Veterans to fit into their busy lives. Future work in this area should focus on developing auditory training programmes which package effective rehabilitation into brief and engaging training sessions which can adapt to the personal schedules of this particular population.

A potential advantage of auditory rehabilitation in young and middle-aged patients with previous TBI is their eagerness to embrace new technologies to improve their daily function. For example, a recent study found that Veterans with mTBI readily accepted FM systems consisting of an ear-level listening device and a separate microphone which could be placed near a talker of interest [32]. Audiologists and speech-language pathologists working with patients with previous blast exposure who have normal or near-normal audiograms have also reported success with prescribing hearing aids to patients who might not usually be prescribed such devices [33]. Results of that study as well as other reports suggest that there may be benefits of providing minimal-amplification gain hearing aids, with or without FM systems, to Veterans with previous blast injury. Benefits have also been reported by patients who have been issued devices such as smartpens which can automatically convert speech into text. Although such reports are promising, evidence-based research is sorely needed to support the use of such technologies among Veterans with head injury.

Overall, research evidence is lacking regarding effective strategies to rehabilitate Veterans with TBI, leaving clinicians to develop new experimental protocols on their own. Providing appropriate care for these Veterans and helping them to understand and solve their communication difficulties requires that the research community focus its efforts on providing the evidence so badly needed by patients and providers alike.

Acknowledgments

Additional Contributions: Marjorie R. Leek, PhD, Robert L. Folmer, PhD, Serena Dann, AuD, and Heather Belding, BS, also contributed to the success of this project. The authors gratefully acknowledge the enthusiastic participation of the Veterans and non-Veterans who volunteered for the studies described in order to improve our understanding of the potential dysfunction afflicting those who have been exposed to high-intensity blasts.

Declaration of interest

This work was supported by the following awards from the United States Department of Veterans Affairs Rehabilitation Research & Development Service (VA RR&D): Merit Review Award C77551 (PIs: Gallun, Leek) and by the VA RR&D National Center for Rehabilitative Auditory Research (C4844C). All work represents the views of the authors and not the official position of the United States Government or the Department of Veterans Affairs.

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Eight tests of the functioning of the central auditory system that have been found to produce abnormal performance among patients with brain injury with the site of lesion verified through imaging technology.

Table 1.

Test	Site of lesion	n	% Abnormal at either ear
Acoustic reflexes ¹	Auditory cortex (either side)	46	26
Auditory brainstem response ¹	Auditory cortex (either side)	46	13
Masking level difference ¹	Auditory cortex (either side)	46	30
Frequency patterns ²	Cortex (either side)	29	83
Gaps-in-noise ³	Brainstem	9	56
	Cortex (either side)	9	78
Staggered spondaic words ⁴	Right primary auditory cortex	51	72
	Left primary auditory cortex	47	66
Dichotic digits ⁴	Right primary auditory cortex	48	41
	Left primary auditory cortex	46	57
Dichotic consonant-vowels ⁴	Right primary auditory cortex	27	79
	Left primary auditory cortex	26	57

Superscript numerical values indicate the reference from which values were taken for each test measure.

¹Jabbari et al. [22].

²Musiek et al. [23].

³Musiek et al. [15].

⁴Mueller et al. [1].