The Application of the International Classification of Functioning, Disability and Health to Functional Auditory Consequences of Mild Traumatic Brain Injury

Kathy R. Vander Werff, Ph.D.[1]

ABSTRACT

This article reviews the auditory consequences of mild traumatic brain injury (mTBI) within the context of the International Classification of Functioning, Disability and Health (ICF). Because of growing awareness of mTBI as a public health concern and the diverse and heterogeneous nature of the individual consequences, it is important to provide audiologists and other health care providers with a better understanding of potential implications in the assessment of levels of function and disability for individual interdisciplinary remediation planning. In consideration of body structures and function, the mechanisms of injury that may result in peripheral or central auditory dysfunction in mTBI are reviewed, along with a broader scope of effects of injury to the brain. The activity limitations and participation restrictions that may affect assessment and management in the context of an individual's personal factors and their environment are considered. Finally, a review of management strategies for mTBI from an audiological perspective as part of a multidisciplinary team is included.

KEYWORDS: Mild traumatic brain injury, hearing, auditory processing, central auditory dysfunction, assessment, rehabilitation, international classification of functioning, disability and health

Learning Outcomes: As a result of this activity, the participant will be able to (1) identify the auditory structures and related functions that may be involved in mild traumatic brain injury and (2) list three ways in

[1]Department of Communication Sciences and Disorders, Syracuse University, Syracuse, New York.

Address for correspondence: Kathy R. Vander Werff, Ph.D., Department of Communication Sciences and Disorders, Syracuse University, 621 Skytop Rd., Suite 1200, Syracuse, NY 13244 (e-mail: kvander@syr.edu).

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which assessment and management of auditory dysfunction may be impacted for an individual in the global context of mild traumatic brain injury.

Awareness of the scope of the public health problem posed by traumatic brain injury (TBI) has grown over the last several years. In particular, it has become apparent that the consequences of mild traumatic brain injury (mTBI) are not at all mild for large proportion of patients, causing serious and lasting functional problems. These problems are numerous and diverse, due to both unique characteristics of the injury and the wide range of preinjury individual factors that may contribute to recovery. The clinical heterogeneity of mTBI therefore requires individualized approaches as well as interprofessional practice collaboration for complete functional assessment and rehabilitation. Because auditory consequences are not uncommon in mTBI, audiology is one of the professions that should be involved in the process.

In 2010, the Centers for Disease Control and Prevention estimated that there were ~2.5 million emergency department visits, hospitalizations, and deaths in the United States due to TBI.[1] These numbers do not include an additional 5.6 million estimated over the years 2000 to 2011 from active service members in all branches of the military diagnosed with a TBI.[2] mTBI accounts for at least 75% of these known injuries.[3] Although the majority recover quickly and fully from mTBI, symptoms of mTBI can persist for months or years for a clinically significant minority of between 1 and 20% of mTBIs.[4–7] The set of long-term symptoms is generally termed postconcussion syndrome, but a lack of definition or diagnostic criteria make it difficult to estimate the actual prevalence. There is growing recognition that for this "miserable minority,"[8] mTBI sustained in sports, combat, accidents, and falls and by other mechanisms has deleterious effects that may not be immediately apparent or predictable, but can substantially alter an individual's life.

The World Health Organization (WHO) task force defines mTBI as an acute brain injury resulting from mechanical energy to the head from external physical forces.[9] The designation "mild" requires a Glasgow Coma Scale score of 13 to 15 after 30 minutes postinjury and one or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, posttraumatic amnesia for less than 24 hours, and/or other transient neurologic abnormalities such as focal signs, seizure, and intracranial lesion not requiring surgery.[10] The terms *mild traumatic brain injury* and *concussion* are generally used interchangeably, with concussion being the more common term in sports. It can be difficult to diagnose mTBI, due to lack of witnesses to the event and/or the individual's own awareness of they were unconscious or for how long. Focal neurologic deficits may not be apparent on any medical testing, including standard medical imaging. Therefore, it is often the case that evidence of mTBI may come from symptoms (physical, cognitive, and behavioral) that alone or in combination may produce functional disability.

A growing body of research suggests that auditory problems are among the wide range of clinical manifestations of mTBI. The effects of hearing and auditory dysfunction on the lives of individuals with mTBI need to be considered and awareness of the functional consequences more widely known by audiologists as well as referring professionals to address all domains of functional health. The WHO's International Classification of Functioning, Disability and Health (ICF) provides a framework to consider the assessment and management needs of the mTBI population across domains to better identify individual needs and goals. The auditory, cognitive, emotional, and behavioral systems all need to be integrated in considering the specific needs for this group of individuals in planning a multidisciplinary comprehensive rehabilitation plan.

The ICF stresses health and functioning, rather than disability and limitations. The model consists of two main parts. *Functioning and disability* includes the components of (1) body structures and physiological functions and (2) activities and participation, and *contextual factors* are divided into environmental and personal factors. Comprehensive management of an individual with mTBI and related auditory dysfunction includes consideration of all of these components. A summary of some of the key components of this model relevant to the auditory consequences of mTBI is shown in Table 1. This review will begin with consideration of the ICF model components of functioning and disability, then consider assessment and management of the audiological consequences of mTBI within this framework.

BODY STRUCTURES AND FUNCTIONS

When the head is struck, the soft tissues of the brain may sustain injury against the bony and sharp ridges of the skull. Due to skull morphology, the frontal and temporal lobe areas are particularly vulnerable to this type of damage. In addition, the brain also may accelerate toward and strike the opposite side of the skull from the impact. Both types of impact, called *coup* and *contrecoup*, respectively, may happen in the same injury and also may occur without impact (such as in whiplash). These types of primary damage can include skull fractures, contusions or bruising, hematoma, laceration, and shearing or tearing of nerve fibers. Specific to the auditory system, focal and direct damage due to an impact or blast to the temporal bone could cause fracture and impact damage to the external, middle, and inner ear. Impact of the brain against bony ridges of the temporal bone can directly affect the primary auditory cortex.[11] In addition to effects on the bottom-up auditory processing pathway, it is also important to consider that brain structures in the vulnerable frontal and temporal lobes involved in cognition, attention, and memory are likely to have top-down influences on the brain's ability to process auditory information.

Diffuse axonal injury (DAI) is one the most common injuries, even in mild traumatic brain injury, caused by the acceleration forces and sliding of tissues against each other leading to shearing damage to axons and swelling. Eventually the swelling may lead to axonal rupture, secondary swelling, and even axonal disconnection and the formation of retraction bulbs. Adjoining neurons then become depolarized eventually leading to excitotoxicity and cell death. DAI occurs most frequently in motor vehicle accidents and following blows to the unsupported head, due to acceleration and deceleration within the skull. The damage is often most severe along midline structures including the corpus callosum and brainstem and at the cortex–white matter junction and increases with the severity of injury. The auditory brainstem nuclei are vulnerable to this type of injury, particularly in acceleration–deceleration and rotational injuries and DAI when more shearing may occur in this area.[12] In nondirect secondary effects, auditory areas have been suggested to be more susceptible to effects of anoxia and ischemia than other brain areas.[13–15] There is also some reported evidence that genes thought involved in age- or noise-related hearing loss may be altered after blast-induced TBI according to animal models, along with significant alterations in the auditory cortex.[16]

The body structures and functions therefore that must be considered relative to auditory consequences of mTBI include structures of the brain and nervous system in general and specifically those within the auditory pathway. Shown in Table 1 are relevant ICF classifications that exist in the model for structures of the nervous system (s1) and the eye, ear, and related structures (s2, i.e., the sensory structures). The related functions of the ICF model on the right side of the table include mental functions (b1) and sensory functions and pain (b2).

CONSIDERATIONS FOR ASSESSMENT OF AUDITORY STRUCTURES AND FUNCTION IN MILD TRAUMATIC BRAIN INJURY

Hearing, Tinnitus, and Dizziness

With the exception of temporal bone fracture, many mild closed head injuries may not result in peripheral hearing loss affecting clinical audiometric measures of sound detection and word recognition in quiet. Blast-associated mTBI injuries, however, may result in damage to the external, middle, and inner ear due to both noise exposure and the pressure of the blast wave. Although some studies have reported a prevalence of peripheral hearing loss of as high as 56% immediately following all severities of

Table 1 Examples of Components of the ICF Model Related to Auditory Consequences of mTBI

Body Structures and Functions		
Structure:		Function:
Structure of the Nervous System (s1) • *Structure of the brain (s110): cortical lobes, midbrain, brainstem, cranial nerves*		*Mental Functions (b1)* • *Global mental functions (b110-b139): intellectual, sleep, consciousness, personality, etc.* • *Specific mental functions (b140-189): attention, memory, perceptual, higher-level cognitive functions, mental functions of language*
The Eye, Ear and Related Structures (s2) • Structure of the external ear (s240) • Structure of middle ear (s250): tympanic membrane, ossicles, Eustachian tube • Structure of inner ear (s260): cochlea, vestibular labyrinth, semicircular canals, internal auditory meatus		Sensory Functions and Pain (b2) • Hearing functions (b230): detection, discrimination, localization, speech recognition • Vestibular functions (b235): position balance, movement • Sensations (b240): tinnitus, dizziness, falling, aural pressure, irritation of the ear
Activities and Participation		
Learning and applying knowledge (d1): *focusing attention (d160), reading (d166), writing (d170)*		
General tasks and demands (d2): *undertaking simple or complex task (d210), multiple tasks (d220), daily routine (d230)*		
Communication (d3): *understanding speech (especially in noise) (d310), conversation (d350), using communication devices and techniques (d360)*		
Mobility (d4): hand and arm use *(d440, 445), walking (d450), moving around (d455), transportation and driving (d470, 475)*		
Self-care (d5): *caring for body, dressing, etc. (d510, 520, 540), looking after one's health (d570)*		
Domestic life (d6): *acquisition of services (d620)*		
Interpersonal interactions and relationships (d7): *complex interpersonal interactions (d720), family relationships (d760)*		
Major life areas (d8): *aspects of employment (d845, 850), education (d820)*		
Community, social and civic life (d9): *community life (d910), recreation and leisure (d920)*		
Environmental Factors		
Products and Technology (e1): *assistive products and technology for personal use, communication, education, and employment (e115, 125, 130, 135)*		
Natural environment and human-made changes to environment (e2): *light (e240), sound (e250)*		
Support and relationships (e3): *immediate family (e310), friends (e320), health and other professionals (e355, 360)*		
Attitudes (e4): *attitudes of immediate family (e410), peers and colleagues (e425), health professionals (e450), societal attitudes (e460)*		
Services, systems and policies (e5): *communication services (e535), health services (e580), education and training (e585)*		
Personal Factors		
Gender	Education	Past and current experience
Age	Profession	Overall behavior patterns
Coping styles	Social background	

Abbreviations: ICF, International Classification of Functioning, Disability and Health; mTBI, mild traumatic brain injury.

TBI, the incidence appears to decrease to 14.5 to 33% during the initial recovery period.[17–21] For mTBI, permanent sensorineural hearing loss is reported much less commonly than for more severe injuries.[22,23] Although peripheral hearing loss is not uncommon following mTBI, studies from both civilian and military populations have shown that many individuals have normal or near-normal audiograms in the long-term following mTBI.[23,24]

Tinnitus is an extremely common symptom following mTBI, either as a direct result of the injury or related to medications used to treat the symptoms of pain, headache, and emotional and cognitive problems. Functionally, tinnitus may be a particularly problematic symptom because of effects on concentration, sleep, irritability, and nervousness already common in individuals after TBI. Several studies have shown that individuals with TBI-induced tinnitus rated their tinnitus as being more severe and distressing than those with non–head injury-related tinnitus.[25–27] Dizziness and loss of balance are also among the most common symptoms following mTBI. Persistent long-term dizziness after mTBI has been estimated to occur from as low as 1.2% at 6 months to up to 32.5% at 5 years.[19,28,29] Balance problems, dizziness, and double vision have been reported in 43 to 77% of postconcussion cases in the sports literature,[30–33] and veterans with mTBI have significantly more vestibular symptoms relative to veterans with no mTBI.[34] Blast-exposed service members with primary blast mTBI may have different patterns of dizziness and even more frequent long-term problems, with up to ~84% of patients presenting with chronic vestibular consequences.[35,36]

As peripheral hearing loss, tinnitus, and dizziness all can be significantly disabling functional problems, a full audiological assessment is warranted for any individuals with specific symptoms as well as those with multiple ongoing postconcussion complaints in general.

Electrophysiologic Evaluation and Evidence of Central Auditory Dysfunction

Some individuals with mTBI may be difficult to test behaviorally due to other cognitive and emotional factors. In some cases, objective assessment, such as auditory brainstem response (ABR) thresholds and otoacoustic emissions, may be used to provide additional diagnostic information of hearing abilities. Auditory evoked potentials, although not able to pinpoint damage and dysfunction within the central auditory system, may offer some insight into dysfunction at different levels of the auditory processing pathway including the brainstem and the auditory cortex.

Several studies have used auditory evoked potentials to evaluate the central auditory system in TBI, although few of these have been restricted to mTBI. At the brainstem level, more severe TBI injuries have commonly been shown to have abnormal click-evoked ABR responses[37–41]; however, significant ABR changes have not always been observed in milder injuries.[42,43] A few published studies have shown prolonged interpeak latencies in individuals with mTBI.[44–47] In recent research, Gallun et al found that click-evoked ABRs in a group of blast-exposed subjects, some of whom were diagnosed with mTBI (19/55), did not differ from those of normal control participants.[48] Vander Werff and Rieger found similar results in a study of 32 civilian participants with mTBI at a whole-group level; however, when those participants with mTBI who had evidence of abnormal central auditory processing by behavioral evaluation were analyzed separately, there was evidence of delayed ABR latencies for both the click- and speech-evoked ABRs.[49] Therefore, although not all individuals will have evidence of abnormal brainstem auditory processing, it appears that some do and this can affect their functional auditory abilities.

At the cortical and cognitive levels of the central auditory pathway, few studies have looked at later obligatory, sensory responses such as the cortical auditory evoked potential (or the long latency response) but a great number of studies used cognitive processing potentials such as the P3. Results from auditory P3 studies that have included individuals with mTBI have also been mixed, with some studies showing that P3 results do not differentiate between mTBI and control groups,[50–52] but others have demonstrated significant changes in P3 latency and/or amplitude in groups with mTBI.[53–56] There is considerable variability in patient and injury demographics as well as in methodology of the P3 studies, which may contribute to whether group differences are found. More complex paradigms than the traditional auditory oddball task may be more sensitive to detect subtle differences after mTBI.[57,58] Recent research from both Gallun et al and Vander Werff and Rieger has shown electrophysiologic evidence of auditory processing changes at the sensory cortical (long latency response, or cortical auditory evoked potential) and cognitive levels (auditory P3) in individuals with mTBI, whether by blast injury or in civilian populations with nonblast mTBI.[48,59]

The heterogeneity of the mTBI population, including factors such as the specific nature of injury and preinjury interindividual factors, makes the lack of consensus across studies regarding group differences in central auditory pathology unsurprising. However, it is apparent that central auditory neural abnormalities are not uncommon consequences for individuals following mTBI.

Behavioral Evaluation of Central Auditory Dysfunction in Mild Traumatic Brain Injury

The functional outcome of pathology in the central auditory system typically relates difficulty with auditory behaviors of sound localization and lateralization, auditory discrimination, pattern recognition, temporal aspects of audition, and performance in the presence of competing acoustic signals and degraded signals. Though limited, existing research suggests that somewhere between 16 and over 50% of individuals who sustain TBI have some evidence of central auditory dysfunction using behavioral test measures.[18,60–63]

Most of these studies were not specific to mTBI, and the participant demographics and outcome measures used across studies are highly variable. More recently, Turgeon et al studied a small group of athletes with concussion/mTBI using a battery that included assessments of tone pattern recognition, identification of synthetic sentences in competing noise, and dichotic listening ability.[64] Five of the eight athletes who had experienced at least one concussion had deficits for one or more of the auditory processing tests. In a military population, blast-exposed participants in the recent Gallun et al study were found to perform abnormally at significantly higher than chance rates on several tests including gap detection in noise, masking level difference, and dichotic listening.[48] Although only a portion of their subjects were diagnosed with mTBI, the authors found no significant correlation between diagnosis of blast exposure with or without mTBI and the number of abnormal auditory behavioral tests. Similarly, Saunders et al reported that blast-exposed veterans with clinically normal hearing as a group had measurably decreased performance on some, but not all, measures of auditory performance including speech understanding in noise, binaural processing, temporal resolution, and speech segregation.[65] In a civilian population (no blast exposure), we also found significant group differences by both raw score and rate of abnormal performance between uninjured controls and participants with mTBI on auditory behavioral evaluations including speech recognition in noise, time-compressed speech, gaps in noise, and dichotic listening.[59] These recent studies provide evidence that even mTBI, whether nonblast or blast induced, can result in specific central auditory processing dysfunction in a significant proportion of individuals postinjury.[48,59,64,65]

The diagnostic term *central auditory processing disorder* is not used here, and caution in its use has been recommended,[66] because it is unlikely that TBI results in damage only to auditory-specific centers in the brain. However, knowing about central auditory manifestations of mTBI is an important part of the evaluation and treatment planning process for audiologists as part of a multidisciplinary team. Although there is no standard battery of tests to thoroughly diagnose central auditory problems in mTBI, a measure of speech in noise, a measure of temporal resolution, and dichotic listening/speech segregation might be minimum items to include.

Self-Report of Functional Hearing Problems and Considerations for Assessment

There are many self-report scales and checklists for concussion symptom measurement in use in sports, U.S. Department of Veterans Affairs (VA)/military, neuropsychology, and other clinical settings seeing individuals with known or suspected mTBI. These scales generally assess many of the common physical (e.g., headache, dizziness, nausea), cognitive (e.g., difficulty concentrating, slowed thinking), and emotional (e.g., irritability, anxiety, depression) postconcussion symptoms. Depression, for instance, is very common after concussion, affecting quality of life and recovery.[67,68] Posttraumatic stress disorder (PTSD) also commonly coexists with mTBI, particularly in the military/VA population.[69,70] In a study of chronic postconcussion symptoms in Operation Enduring Freedom/Operation Iraqi Freedom veterans, Verfaellie et al reported that participants endorsed considerable limitations on a comprehensive health-related quality-of-life measure, particularly in psychosocial domains, and that the impact of PTSD and depression was seen across physical, cognitive, and emotional symptoms.[71]

Functional hearing and central auditory problems have not often been reported in a systematic way in the mTBI population. Postconcussion questionnaires often include questions about tinnitus, dizziness, and sensitivity to sound among their physical symptoms. Saunders et al included a Functional Hearing Questionnaire (FHQ) developed by the authors and the Speech, Spatial and Qualities Questionnaire (SSQ) to assess the listening problems of veterans with mTBI and normal or near-normal audiograms.[65,72] They found that understanding speech in noise was the most common problem, with over 75% of participants reporting problems in the area. Other challenging items included difficulty following long conversations, difficulty understanding fast speech, and difficulty on the telephone. SSQ scores for the participants with mTBI when compared with data from other published studies indicated listening problems similar in magnitude to those of older adults with hearing loss and worse than those of young or older normal-hearing adult studies.[72,73] Using a similar auditory symptom questionnaire (a modified, unpublished version of the FHQ containing 12 items) in our study of civilians,[74] we found that those with mTBI endorsed a high number of both auditory and postconcussion symptoms. The mTBI group scored higher than the control group on each of the 12 questions, and the average score for 7 of 12 questions indicated that the majority of symptoms were experienced "sometimes" or "all the time." Similar to the Saunders et al study, increased sensitivity to loud sound, difficulty hearing in noise, and difficulty understanding rapid or muffled speech were among the most reported problems.[65] Two other commonly indicated problems by the subjects with mTBI on this version of the questionnaire were difficulties paying attention when people talk and difficulty memorizing information obtained by listening. These items may relate more directly to cognitive top-down function than auditory processing. Overall, scores on the auditory questionnaire were fairly strongly correlated with those on other postconcussion symptom questionnaires including the Rivermead Post-Concussion Symptoms Questionnaire ($r = 0.79$),[75] the Beck Depression Inventory ($r = 0.64$),[76] and the Fatigue Severity Scale ($r = 0.70$).[77] The more symptoms the person reports overall, the more he or she also reports what are considered auditory symptoms.

Self-report measures of functional hearing and auditory processing problems are recommended for use with patients with mTBI, although there are no standardized measures specific to this population. However, measures such as the FHQ reported by Saunders et al and other measures of handicap commonly used in audiology for hearing-impaired individuals, elderly individuals, and those with auditory processing problems may be useful in assessing the individual functional auditory problems experienced by this population.[65] The Hearing Handicap Inventory for the Elderly,[78] Hearing Handicap Inventory for Adults,[79,80] SSQ,[72] or other measures may be utilized along with thorough case history to assess the functional problems that may not be obvious when looking at the pure tone audiogram and speech recognition in quiet alone. The Tinnitus Handicap Inventory and Dizziness Handicap Inventory may be valuable tools for the audiologist to use in planning remediation and referrals.[81,82]

General Assessment Considerations for Audiologists Working with Individuals with Mild Traumatic Brain Injury

Some of the reported auditory problems may be related to or exacerbated by emotional and cognitive symptoms and problems. It is clear that mTBI is frequently associated with cognitive problems such as reduced processing speed and deficits in attention, orientation, executive function, and language, which would affect an individual's ability to process auditory information, as well as other modalities. It is important for audiologists to take into consideration the more global deficits that may contribute to or make it difficult to accurately measure auditory function. For instance, problems with attention, memory, and executive functioning may make it difficult for individuals with mTBI to complete portions of auditory testing, particularly some of the more complex central auditory tasks. Neuropsychologists may have completed a host of tests and questionnaires to assess these specific mental functions and emotional states in their assessments. Another important factor can be poor effort, or symptom exaggeration, which has been found to be relatively common in mTBI and associated with reduced test performance on neuropsychological tests.[83] Approximately 20% of adults with mTBI fail effort screening tests,[84] which would make behavioral test results uninterpretable, including auditory tests. In our study, we found evidence of effort failure in 4 of the 32 individuals with mTBI and chronic postconcussion problems, or 12.5%.[59] Working with information from the entire multidisciplinary team may help audiologists better determine how to perform and interpret tests in light of some of these more complex factors.

Other frequently reported physical symptoms may affect the individual's ability to complete testing or treatment protocols. Sensitivity to both light and sound are extremely common, and mTBI patients may require or appreciate a darkened, quiet room free from any auditory or visual distraction. Anxiety about testing and performance, inability to concentrate, and fatigue may necessitate short test intervals with frequent breaks. Patients with mTBI may also experience language problems, including difficulty with word retrieval and difficulty reading and writing. Difficulty with movement and slower response speeds may also require modification of some testing to allow for timed responses. Vision problems may also be present and influence auditory testing and treatment. Data have shown that dual-sensory impairments are more common in blast-related TBI than non-TBI VA patients, and that dual-sensory impairment is seen in those with TBI at earlier ages than in the traditional non-TBI population.[85,86] In addition to each unimodal deficit, the ability to integrate multisensory input has also been shown to be reduced in TBI.[87] Measures to assess ability to integrate auditory and visual information may be useful to more fully assess some individuals.

Problems with pain, particularly headache, low back, and neck pain, are frequently reported in patients with mTBI. A systematic review of studies including 1,046 individuals (both civilian and military) with a history of mTBI found a pain prevalence rate of 75%.[88] Emotional distress, including depression and anxiety, are linked with increased pain and a decrease in a person's ability to cope with their pain.[89,90] Chronic pain, PTSD, and postconcussion symptoms have been termed a highly prevalent clinical triad among Operation Enduring Freedom/Operation Iraqi Freedom veterans.[70] The interaction among all of these can make diagnosis and treatment planning difficult, but audiologists should be sensitive to these factors when considering the test environment and tasks they use in assessing each individual.

ACTIVITIES AND PARTICIPATION RELATED TO AUDITORY CONSEQUENCES OF MILD TRAUMATIC BRAIN INJURY

Because mTBI can affect any area of the brain, the number of categories of activities and participation that can influence daily function and quality of life are large and varied. Hearing and auditory processing problems also can impose their own broad activity limitations and participation restrictions. Many of the functional problems addressed in the previous section relate to disability and restrictions the patient may perceive, but they depend highly on the contextual factors, both environmental and personal, unique to each person.

There are a variety of assessment tools (reviewed by Tate et al[91]) that might be used in interdisciplinary assessment of aspects of activities and participation, including multidimensional tests and specific tests of areas such as communication abilities, mobility issues, interpersonal interactions and relationships, and daily living skills. Many with long-term post-concussion syndrome have been unable to return to work, school, or other activities for many weeks or months due to their ongoing symptoms and may be further isolated by avoiding social interaction. Focus group studies confirm that some of the most common activity and participation concerns in individuals with mTBI were related to carrying out daily routines, work/employment, mobility, aspects of health and self-care, recreation and leisure, and interpersonal/social interactions.[92,93] Although not among the highest categories in either study, items under the category of communication were regularly noted including speaking, writing messages, and using communication devices and techniques.[93] Communication would undoubtedly be highly related to functions associated with interpersonal interactions, which were frequently noted in both studies. Another important category related to learning and applying knowledge highlighted difficulties with watching, focusing attention, and solving problems.[93]

There have not been specific studies of activities and participation limitations due to auditory consequences of mTBI, but data about the most common activities and limitations reported by older adults with hearing loss provide some insight into additional areas and overlap that may be seen in the mTBI population experience auditory problems. The most common activity limitations for this group are difficulty understanding speech especially in noisy situations, difficulty with conversation, informal social relationships and community life, and difficulties with television and radio listening and social situations.[94] There is considerable overlap among these lists, and although they may be for different reasons in some cases, it is reasonable to consider that some of the daily activity limitations and participation restrictions across groups relate to difficulties with hearing and auditory information.

Environmental and personal factors are considered contextual factors under the ICF model. These factors influence the impairments due to body function and structure, activity limitations, and participation restrictions and the relationship among all of these. Although personal factors are not coded in the model, these are factors such as demographic variables, personality characteristics, and a person's background experiences. Audiologists are familiar with the influence of factors such as age and different coping styles and their influence on things like accepting technology and rehabilitation, such as discussed in Cox et al.[95] For mTBI, age and gender may influence outcomes and recovery. Although mTBI is more common in males, women of childbearing age (not younger or older females) tend to report more post-TBI symptoms than males.[96,97] Age over 40 also may be a factor in poorer outcomes after mTBI.[9,98]

A complexity in mTBI can be that both preexisting personality traits and changes in personality due to the injury, as well as mood and emotional factors associated with postconcussion symptoms, can influence recovery outcomes. Included in these factors is how the individuals perceive their health status and quality of life, which may be very different even given similar test outcomes. For example, individuals with mTBI may place more or less emphasis on their perceived auditory problems depending on factors such as the importance they place on their work, social activities, or other parts of daily life. Remediation therefore needs to be patient-centered to address the individual factors that will influence their perceptions and experiences.

Environmental factors are things in the physical, social, and attitudinal environment that may facilitate or provide barriers to function (or both). Sveen et al found that some of the most common environmental categories noted as barriers and/or facilitators by focus groups with mTBI included products and technology for daily living and communication, and the overall category of sound.[93] Other common areas included friends, family, and acquaintances, as well as people in authority and health professionals. In most cases, immediate family is considered an important facilitator and means of support.[92]

Some contextual factors unique to mTBI compared with other populations seen by audiologists may include how the injury was sustained, such as whether in a traumatic event, and whether the individual is part of any legal proceedings or seeking compensation related to their injury. Many individuals have not been able to return to work, school, or sports for significant periods of time, often longer than expected. In addition to stressors related to the injury and the aftermath, they may have concurrent family and life stressors. Many individuals will be seeing multiple health professionals, social service providers, legal professionals, and vocational or educational consultants to address their varied circumstances. Drug and alcohol use may present issues as substance use disorders often co-occur with TBI postinjury and are also highly associated as risk factors for sustaining head injury that may contribute to outcomes.[99,100]

MANAGEMENT OF AUDITORY CONSEQUENCES OF MILD TRAUMATIC BRAIN INJURY

At this time, there is little research specifically related to the management and remediation of auditory effects of mTBI. However, the fields of audiology and speech-language have considerable applicable experience based on what we know about remediation with individuals with hearing loss, perhaps particularly older adults with hearing loss and cognitive decline, central auditory processing in children and adults, and cognitive communication rehabilitation in general. The American Speech-Language Hearing Association addresses the roles of audiologists and speech-language pathologists in the assessment, diagnosis, and rehabilitation of individuals with TBI according to their respective scopes of practice.[101]

An important consideration in rehabilitation for TBI is that rest and management of physical and cognitive symptoms are first priorities. Fatigue and stress are important to consider because individuals with traumatic brain injury may be simultaneously receiving rehabilitation services from various professionals to address a range of functional needs including educational, psychological, cognitive, vocational, communication, and medical therapies. All of these areas would likely be more effectively addressed if the clinicians involved were aware of any hearing or auditory processing difficulties. Addressing their audiological needs can allow for individuals to have greater participation in their other therapies and activities of daily living. Improvements in auditory processing may combine with improvements in attention, auditory memory, or other cognitive abilities to improve overall quality of life and educational/vocational benefit.

Audiological management of peripheral hearing loss in mTBI should follow established best clinical practices, with considerations for any concomitant symptoms and functional problems as discussed above. Fitting of hearing aids or assistive devices may need to be modified based on the activities, participation, and environmental factors discussed previously. Audiologists can use knowledge gained from management of hearing loss in older adults, individuals with central auditory processing disorders, and populations with multiple functional disabilities to better address the individual needs of patients with mTBI.

Approaches to management of tinnitus may be especially important to consider and individualize for those who have experienced mTBI. Some evidence has shown that although groups with TBI rated tinnitus as more severe, there was no difference between groups with and without head injury in the pitch and complexity of the tinnitus, masking level, and acceptance of wearable maskers.[25] Therefore, management may rely on the same tools, but other factors such as higher rates of sleep issues, anxiety, depression, and PTSD may require modification to treatment and counseling protocols and a multidisciplinary approach to simultaneously address these functional considerations. Tinnitus treatment programs such Progressive Tinnitus Management or Tinnitus Retraining Therapy may provide foundations that can be modified to the needs of the individual with mTBI.[102,103] A pilot study on the use of a telehealth Progressive Tinnitus Management program has been conducted with groups from the VA with mTBI, moderate to severe TBI, and a comparison group with no TBI.[104] The three groups showed similar improvement in their Tinnitus Handicap Inventory scores, showing that this type of program can be effective in addressing the needs of individuals with mTBI.[81] A follow-up clinical trial is being conducted to better identify possible group differences and evaluate the efficacy of telehealth, which may provide clinicians additional guidelines for addressing the functional problems in the mTBI population, whether military or civilian.

Similarly, management of dizziness and balance will be important considerations for a comprehensive rehabilitation management program for many individuals with mTBI. Weightman and Leuty presented guidelines on vestibular testing including evaluations audiologists may be perform in a vestibular laboratory such as electronystagmography, rotary chair testing, and vestibular evoked myogenic potentials with the goal of determining whether findings are consistent with vestibular pathology (either peripheral or central).[105] Other clinical examinations, which may be performed by other professionals such as physical therapists or physicians, may include patient self-report measures such as the Dizziness Handicap Inventory,[82] gait analysis, neurologic evaluations, positional testing, computerized dynamic posturography, and oculomotor examination. Taken together, these tests can be used to determine a plan of care that may include vestibular physical therapy such as canalith repositioning techniques or postural stability training. Provision of vestibular rehabilitation improves outcomes and shortens disability times in patients with mTBI.[106,107] A review of individualized treatment recommendations can be found in Weightman and Leuty to address positional vertigo, unilateral vestibular hypofunction, and treatment of motion sensitivity and exercise-induced dizziness from a physical therapy perspective.[105]

MANAGEMENT OF AUDITORY PROCESSING PROBLEMS

Approaches to management of auditory processing problems are not standardized and are often geared toward developmental auditory processing disorders. Intervention approaches for auditory processing dysfunction have generally been divided into categories of environmental modifications, compensatory strategies, and direct skills remediation.[108] These areas fit well into the ICF model of remediating the disorder (body function), changing the environment, and increasing a person's ability to participate in activities of daily life.

Direct remediation of function would include auditory training with the hope of inducing neurophysiological changes and improved auditory skills. There is currently very little in the way of outcomes research for this type of bottom-up rehabilitation approach specific to mTBI. Software programs based on neuroplasticity geared toward overall training to improved attention, memory, and other cognitive processing abilities exist that target the auditory modality, such as Brain Fitness and the online BrainHQ (both from Posit Science). Although final results are not yet available, a clinical trial in the VA utilizing the Brain Fitness auditory training program reported preliminary benefit to combining such training with the provision of frequency modulation (FM) systems.[109] Research in older adults has demonstrated that there is evidence of at least short-term plasticity following a similar auditory-based cognitive training protocol, but that speech-in-noise and memory gains were not maintained 6 months later.[110] There are also auditory training programs that address specific auditory processing skills that have been used in adults with auditory processing disorders, such as Listening and Communication Enhancement and the Auditory Rehabilitation for Interaural Symmetry.[111,112]

Environmental modifications for individuals with mTBI from an auditory perspective would focus on improving access to and clarity of sound, better signal-to-noise ratio, and ways to increase an individual's ability to listen and learn from auditory signals. These types of modifications can and should go hand in hand with cognitive training strategies used by other members of the rehabilitation team. Amplification, when appropriate, and assistive technology can be used to help improve the acoustic signal and ease of listening. Remote microphone and FM technology may be useful, even for individuals with clinically normal hearing, possibly coupled with a low-gain hearing aid. FM system use has been established as an effective rehabilitation tool for improving speech perception in noise hearing-impaired children and adults,[113–116] as well as for children with auditory processing disorders and normal hearing sensitivity.[117,118] Saunders et al reported on the use of an FM system as part of the rehabilitation program in three patients with blast exposure and head injuries who had normal peripheral hearing but significant complaints of auditory difficulty.[119] Although a very small sample, two of the three cases reported positive experiences with the FM system, showed higher improvement scores on questionnaire scales, and were interested in continuing to use it after the study concluded. Other environmental modifications would include strategies such as workplace and educational setting accommodations. Use of preferential seating to maximize auditory and visual information, acoustic modifications to reduce noise interference, consideration of note takers, and having information provided in writing instead of just verbally can be simple but useful strategies.

Compensatory strategies are another important area to consider. Examples would include having the individual repeat back instructions they heard to check comprehension and to rephrase and restate when he or she does not understand. Students and individuals in certain work settings may benefit from reading ahead (agenda, outline, or text) so they are familiar with what will be discussed in a class or meeting. Involvement of family, teachers, employers, coworkers, and other communication partners in management efforts is an important component, such as requesting that they use clear speech, initiate conversation in more conducive locations, and making sure their faces can be seen.

Audiologists will need to collaborate with other members of a multidisciplinary rehabilitation team that may include cognitive and/or communication therapists. Reviewing results of a neuropsychological exam may be useful in interpreting test results and planning treatment. It has been stressed recently that cognitive communication rehabilitation should focus on application of compensatory strategies to real-life situations and that treatment should be realistic and generalizable to natural environments and daily routines.[120] Auditory rehabilitation may be integrated into and borrow from the interventions that neuropsychologists or speech-language pathologists pursue as part of cognitive training and communication rehabilitation. For instance, the use of personal digital assistants and smartphones may be an important tool to help patients remember information they hear and combine auditory and visual cues (such as an alarm). Communication strategies may be an important tool to work on language skills as well as coping with difficulties hearing in noise. In another interdisciplinary example, Saunders and Echt provided a useful review of rehabilitation factors that may be important to consider when working with individuals in the military with dual-sensory impairment.[121] The ultimate goals of reducing activity limitations and participation restrictions and enhancing quality of life are likely more broadly applicable to the general mTBI population, including civilians with mTBI from falls, motor vehicle accidents, sports, and other mechanisms.

CONCLUSION

There is growing evidence that mTBI can affect structures in the auditory pathway and have functional auditory consequences for some individuals in the long term. Audiologists have the tools necessary for assessment and management of these auditory problems within the context of a multidisciplinary team. Because mTBI is marked by heterogeneity, the ICF model allows consideration of the body structures and function as well as the contextual factors that are unique to each individual and their remediation plan.

REFERENCES

1. Centers for Disease Control and Prevention (CDC). Report to Congress on Traumatic Brain Injury in the United States: Epidemiology and Rehabilitation. Atlanta, GA: National Center for Injury Prevention and Control; Division of Unintentional Injury Prevention; 2014
2. CDC, NIH, DOD, and VA Leadership Panel. Report to Congress on Traumatic Brain Injury in the United States: Understanding the Public Health Problem among Current and Former Military Personnel. Centers for Disease Control and Prevention (CDC), the National Institutes of Health (NIH), the Department of Defense (DOD), and the Department of Veterans Affairs (VA). 2013. Available at: https://stacks.cdc.gov/view/cdc/28994. Accessed June 7, 2016
3. National Center for Injury Prevention and Control. Report to Congress on Mild Traumatic Brain

Injury in the United States: Steps to Prevent a Serious Public Health Problem. Atlanta, GA: Centers for Disease Control and Prevention; 2003
4. Dikmen S, McLean A, Temkin N. Neuropsychological and psychosocial consequences of minor head injury. J Neurol Neurosurg Psychiatry 1986; 49(11):1227–1232
5. Katz RT, DeLuca J. Sequelae of minor traumatic brain injury. Am Fam Physician 1992;46(5): 1491–1498
6. Rimel RW, Giordani B, Barth JT, Boll TJ, Jane JA. Disability caused by minor head injury. Neurosurgery 1981;9(3):221–228
7. Iverson GL. Outcome from mild traumatic brain injury. Curr Opin Psychiatry 2005;18(3):301–317
8. Ruff RM, Crouch JA, Tröster AI, et al. Selected cases of poor outcome following a minor brain trauma: comparing neuropsychological and positron emission tomography assessment. Brain Inj 1994;8(4):297–308
9. Carroll LJ, Cassidy JD, Peloso PM, et al; WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. Prognosis for mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004;43(Suppl): 84–105
10. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. Lancet 1974;2(7872):81–84
11. Gutierrez-Cadavid JE. Imaging of head trauma. In: Latchow RE, Kucharczyk J, Moselely ME, eds Imaging of the Nervous System. Philadelphia, PA: Elsevier Mosby; 2005:869–904
12. Gennarelli TA, Graham DI. Neuropathology of the head injuries. Semin Clin Neuropsychiatry 1998;3(3):160–175
13. Duncan CC, Kosmidis MH, Mirsky AF. Closed head injury-related information processing deficits: an event-related potential analysis. Int J Psychophysiol 2005;58(2–3):133–157
14. Landau WM, Freygang WH Jr, Roland LP, Sokoloff L, Kety SS. The local circulation of the living brain; values in the unanesthetized and anesthetized cat. Trans Am Neurol Assoc 1955–1956;(80th Meeting):125–129
15. Sokoloff L. Localization of functional activity in the central nervous system by measurement of glucose utilization with radioactive deoxyglucose. J Cereb Blood Flow Metab 1981;1(1):7–36
16. Valiyaveettil M, Alamneh Y, Miller SA, et al. Preliminary studies on differential expression of auditory functional genes in the brain after repeated blast exposures. J Rehabil Res Dev 2012;49(7): 1153–1162
17. Abd al-Hady MR, Shehata O, el-Mously M, Sallam FS. Audiological findings following head trauma. J Laryngol Otol 1990;104(12):927–936
18. Cockrell JL, Gregory SA. Audiological deficits in brain-injured children and adolescents. Brain Inj 1992;6(3):261–266
19. Griffiths MV. The incidence of auditory and vestibular concussion following minor head injury. J Laryngol Otol 1979;93(3):253–265
20. Jury MA, Flynn MC. Auditory and vestibular sequelae to traumatic brain injury: a pilot study. N Z Med J 2001;114(1134):286–288
21. Vartiainen E, Karjalainen S, Kärjä J. Auditory disorders following head injury in children. Acta Otolaryngol 1985;99(5–6):529–536
22. Barber HO. Head injury audiological and vestibular findings. Ann Otol Rhinol Laryngol 1969; 78(2):239–252
23. Munjal SK, Panda NK, Pathak A. Relationship between severity of traumatic brain injury (TBI) and extent of auditory dysfunction. Brain Inj 2010; 24(3):525–532
24. Oleksiak M, Smith BM, St Andre JR, Caughlan CM, Steiner M. Audiological issues and hearing loss among veterans with mild traumatic brain injury. J Rehabil Res Dev 2012;49(7):995–1004
25. Vernon JA, Press LS. Characteristics of tinnitus induced by head injury. Arch Otolaryngol Head Neck Surg 1994;120(5):547–551
26. Folmer RL, Griest SE. Chronic tinnitus resulting from head or neck injuries. Laryngoscope 2003; 113(5):821–827
27. Kreuzer PM, Landgrebe M, Schecklmann M, Staudinger S, Langguth B; TRI Database Study Group. Trauma-associated tinnitus: audiological, demographic and clinical characteristics. PLoS ONE 2012;7(9):e45599
28. Kisilevski V, Podoshin L, Ben-David J, et al. Results of otovestibular tests in mild head injuries. Int Tinnitus J 2001;7(2):118–121
29. Masson F, Maurette P, Salmi LR, et al. Prevalence of impairments 5 years after a head injury, and their relationship with disabilities and outcome. Brain Inj 1996;10(7):487–497
30. Gottshall K, Drake A, Gray N, McDonald E, Hoffer ME. Objective vestibular tests as outcome measures in head injury patients. Laryngoscope 2003;113(10):1746–1750
31. Kleffelgaard I, Roe C, Soberg HL, Bergland A. Associations among self-reported balance problems, post-concussion symptoms and performance-based tests: a longitudinal follow-up study. Disabil Rehabil 2012;34(9):788–794
32. Lovell M, Collins M, Bradley J. Return to play following sports-related concussion. Clin Sports Med 2004;23(3):421–441, ix
33. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. JAMA 2003; 290(19):2549–2555

34. Baldassarre M, Smith B, Harp J, et al. Exploring the relationship between mild traumatic brain injury exposure and the presence and severity of postconcussive symptoms among veterans deployed to Iraq and Afghanistan. PM R 2015; 7(8):845–858
35. Hoffer ME, Balaban C, Gottshall K, Balough BJ, Maddox MR, Penta JR. Blast exposure: vestibular consequences and associated characteristics. Otol Neurotol 2010;31(2):232–236
36. Akin FW, Murnane OD. Head injury and blast exposure: vestibular consequences. Otolaryngol Clin North Am 2011;44(2):323–334, viii
37. Fligor BJ, Cox LC, Nesathurai S. Subjective hearing loss and history of traumatic brain injury exhibits abnormal brainstem auditory evoked response: a case report. Arch Phys Med Rehabil 2002;83(1):141–143
38. Greenberg RP, Becker DP, Miller JD, Mayer DJ. Evaluation of brain function in severe human head trauma with multimodality evoked potentials. Part 2: Localization of brain dysfunction and correlation with posttraumatic neurological conditions. J Neurosurg 1977;47(2):163–177
39. Hall JW III, Huangfu M, Gennarelli TA, Dolinskas CA, Olson K, Berry GA. Auditory evoked responses, impedance measures, and diagnostic speech audiometry in severe head injury. Otolaryngol Head Neck Surg 1983; 91(1):50–60
40. Munjal SK, Panda NK, Pathak A. Dynamics of hearing status in closed head injury. J Neurotrauma 2010;27(2):309–316
41. Ottaviani F, Almadori G, Calderazzo AB, Frenguelli A, Paludetti G. Auditory brain-stem (ABRs) and middle latency auditory responses (MLRs) in the prognosis of severely head-injured patients. Electroencephalogr Clin Neurophysiol 1986;65(3):196–202
42. Nölle C, Todt I, Seidl RO, Ernst A. Pathophysiological changes of the central auditory pathway after blunt trauma of the head. J Neurotrauma 2004;21(3):251–258
43. Schoenhuber R, Gentilini M, Orlando A. Prognostic value of auditory brain-stem responses for late postconcussion symptoms following minor head injury. J Neurosurg 1988;68(5):742–744
44. Noseworthy JH, Miller J, Murray TJ, Regan D. Auditory brainstem responses in postconcussion syndrome. Arch Neurol 1981;38(5):275–278
45. Rowe MJ III, Carlson C. Brainstem auditory evoked potentials in postconcussion dizziness. Arch Neurol 1980;37(11):679–683
46. Schoenhuber R, Gentilini M. Auditory brain stem responses in the prognosis of late postconcussional symptoms and neuropsychological dysfunction after minor head injury. Neurosurgery 1986; 19(4):532–534
47. Soustiel JF, Hafner H, Chistyakov AV, Barzilai A, Feinsod M. Trigeminal and auditory evoked responses in minor head injuries and post-concussion syndrome. Brain Inj 1995;9(8):805–813
48. Gallun FJ, Diedesch AC, Kubli LR, et al. Performance on tests of central auditory processing by individuals exposed to high-intensity blasts. J Rehabil Res Dev 2012;49(7):1005–1025
49. Vander Werff KR, Rieger B. Post-concussion brainstem neural processing in quiet and noise. Paper presented at the 37th Annual Midwinter Research Meeting, Association for Research in Otolaryngology; February 22–26, 2014; San Diego, CA
50. Potter DD, Bassett MR, Jory SH, Barrett K. Changes in event-related potentials in a three-stimulus auditory oddball task after mild head injury. Neuropsychologia 2001;39(13):1464–1472
51. Sivák S, Kurca E, Hladká M, Zelenák K, Turcanová-Koprusáková M, Michalik J. Early and delayed auditory oddball ERPs and brain MRI in patients with MTBI. Brain Inj 2008;22(2): 193–197
52. Werner RA, Vanderzant CW. Multimodality evoked potential testing in acute mild closed head injury. Arch Phys Med Rehabil 1991;72(1):31–34
53. Alberti A, Sarchielli P, Mazzotta G, Gallai V. Event-related potentials in posttraumatic headache. Headache 2001;41(6):579–585
54. Papanicolaou AC, Levin HS, Eisenberg HM, Moore BD, Goethe KE, High WM Jr. Evoked potential correlates of posttraumatic amnesia after closed head injury. Neurosurgery 1984;14(6): 676–678
55. Segalowitz SJ, Bernstein DM, Lawson S. P300 event-related potential decrements in well-functioning university students with mild head injury. Brain Cogn 2001;45(3):342–356
56. Solbakk AK, Reinvang I, Andersson S. Assessment of P3a and P3b after moderate to severe brain injury. Clin Electroencephalogr 2002;33(3): 102–110
57. Thériault M, De Beaumont L, Gosselin N, Filipinni M, Lassonde M. Electrophysiological abnormalities in well functioning multiple concussed athletes. Brain Inj 2009;23(11):899–906
58. Wilson MJ, Harkrider AW, King KA. The effects of visual distracter complexity on auditory evoked p3b in contact sports athletes. Dev Neuropsychol 2014;39(2):113–130
59. Vander Werff KR, Rieger B. Cortical auditory processing in individuals with long-term symptoms following mild TBI. Paper presented at: 36th Annual Midwinter Research Meeting, Association for Research in Otolaryngology; February 16–20, 2013; Baltimore, MD
60. Bergemalm PO. Progressive hearing loss after closed head injury: a predictable outcome? Acta Otolaryngol 2003;123(7):836–845

61. Bergemalm PO, Borg E. Long-term objective and subjective audiologic consequences of closed head injury. Acta Otolaryngol 2001;121(6):724–734
62. Bergemalm PO, Lyxell B. Appearances are deceptive? Long-term cognitive and central auditory sequelae from closed head injury. Int J Audiol 2005;44(1):39–49
63. Flood GM, Dumas HM, Haley SM. Central auditory processing and social functioning following brain injury in children. Brain Inj 2005;19(12):1019–1026
64. Turgeon C, Champoux F, Lepore F, Leclerc S, Ellemberg D. Auditory processing after sport-related concussions. Ear Hear 2011;32(5):667–670
65. Saunders GH, Frederick MT, Arnold M, Silverman S, Chisolm TH, Myers P. Auditory difficulties in blast-exposed Veterans with clinically normal hearing. J Rehabil Res Dev 2015;52(3):343–360
66. Dennis KC. Current perspectives on traumatic brain injury. American Speech-Language-Hearing Association Access Audiology 2009;8(4):118
67. Alderfer BS, Arciniegas DB, Silver JM. Treatment of depression following traumatic brain injury. J Head Trauma Rehabil 2005;20(6):544–562
68. Vargas G, Rabinowitz A, Meyer J, Arnett PA. Predictors and prevalence of postconcussion depression symptoms in collegiate athletes. J Athl Train 2015;50(3):250–255
69. Lew HL, Cifu DX, Sigford B, Scott S, Sayer N, Jaffee MS. Team approach to diagnosis and management of traumatic brain injury and its comorbidities. J Rehabil Res Dev 2007;44(7):vii–xi
70. Lew HL, Otis JD, Tun C, Kerns RD, Clark ME, Cifu DX. Prevalence of chronic pain, posttraumatic stress disorder, and persistent postconcussive symptoms in OIF/OEF veterans: polytrauma clinical triad. J Rehabil Res Dev 2009;46(6):697–702
71. Verfaellie M, Lafleche G, Spiro A III, Tun C, Bousquet K. Chronic postconcussion symptoms and functional outcomes in OEF/OIF veterans with self-report of blast exposure. J Int Neuropsychol Soc 2013;19(1):1–10
72. Gatehouse S, Noble W. The Speech, Spatial and Qualities of Hearing Scale (SSQ). Int J Audiol 2004;43(2):85–99
73. Banh J, Singh G, Pichora-Fuller MK. Age affects responses on the Speech, Spatial, and Qualities of Hearing Scale (SSQ) by adults with minimal audiometric loss. J Am Acad Audiol 2012;23(2):81–91, quiz 139–140
74. Beebe D. Self-Reported Symptoms of Central Auditory Processing Dysfunction Following Mild Traumatic Brain Injury. Syracuse University Honors Program Capstone Projects. Syracuse, NY: Syracuse University; 2013
75. Eyres S, Carey A, Gilworth G, Neumann V, Tennant A. Construct validity and reliability of the Rivermead Post-Concussion Symptoms Questionnaire. Clin Rehabil 2005;19(8):878–887
76. Beck AT, Steer RA, Brown GK. Manual for Beck Depression Inventory II (BDI-II). San Antonio, TX: Psychology Corporation; 1996
77. Krupp LB, LaRocca NG, Muir-Nash J, Steinberg AD. The fatigue severity scale. Application to patients with multiple sclerosis and systemic lupus erythematosus. Arch Neurol 1989;46(10):1121–1123
78. Ventry IM, Weinstein BE. The hearing handicap inventory for the elderly: a new tool. Ear Hear 1982;3(3):128–134
79. Newman CW, Weinstein BE, Jacobson GP, Hug GA. Test-retest reliability of the hearing handicap inventory for adults. Ear Hear 1991;12(5):355–357
80. Newman CW, Weinstein BE, Jacobson GP, Hug GA. The Hearing Handicap Inventory for Adults: psychometric adequacy and audiometric correlates. Ear Hear 1990;11(6):430–433
81. Newman CW, Jacobson GP, Spitzer JB. Development of the Tinnitus Handicap Inventory. Arch Otolaryngol Head Neck Surg 1996;122(2):143–148
82. Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory. Arch Otolaryngol Head Neck Surg 1990;116(4):424–427
83. Stulemeijer M, Andriessen TM, Brauer JM, Vos PE, Van Der Werf S. Cognitive performance after mild traumatic brain injury: the impact of poor effort on test results and its relation to distress, personality and litigation. Brain Inj 2007;21(3):309–318
84. Carone DA. Children with moderate/severe brain damage/dysfunction outperform adults with mild-to-no brain damage on the Medical Symptom Validity Test. Brain Inj 2008;22(12):960–971
85. Lew HL, Garvert DW, Pogoda TK, et al. Auditory and visual impairments in patients with blast-related traumatic brain injury: effect of dual sensory impairment on Functional Independence Measure. J Rehabil Res Dev 2009;46(6):819–826
86. Smith SL, Bennett LW, Wilson RH. Prevalence and characteristics of dual sensory impairment (hearing and vision) in a veteran population. J Rehabil Res Dev 2008;45(4):597–609
87. Sarno S, Erasmus LP, Lipp B, Schlaegel W. Multisensory integration after traumatic brain injury: a reaction time study between pairings of vision, touch and audition. Brain Inj 2003;17(5):413–426
88. Nampiaparampil DE. Prevalence of chronic pain after traumatic brain injury: a systematic review. JAMA 2008;300(6):711–719

89. Sherbourne CD, Asch SM, Shugarman LR, et al. Early identification of co-occurring pain, depression and anxiety. J Gen Intern Med 2009;24(5):620–625
90. Tunks ER, Crook J, Weir R. Epidemiology of chronic pain with psychological comorbidity: prevalence, risk, course, and prognosis. Can J Psychiatry 2008;53(4):224–234
91. Tate RL, Godbee K, Sigmundsdottir L. A systematic review of assessment tools for adults used in traumatic brain injury research and their relationship to the ICF. NeuroRehabilitation 2013;32(4):729–750
92. Pistarini C, Aiachini B, Coenen M, Pisoni C; Italian Network. Functioning and disability in traumatic brain injury: the Italian patient perspective in developing ICF Core Sets. Disabil Rehabil 2011;33(23–24):2333–2345
93. Sveen U, Ostensjo S, Laxe S, Soberg HL. Problems in functioning after a mild traumatic brain injury within the ICF framework: the patient perspective using focus groups. Disabil Rehabil 2013;35(9):749–757
94. Hickson L, Scarinci N. Older adults with acquired hearing impairment: applying the ICF in rehabilitation. Semin Speech Lang 2007;28(4):283–290
95. Cox RM, Alexander GC, Gray GA. Who wants a hearing aid? Personality profiles of hearing aid seekers. Ear Hear 2005;26(1):12–26
96. Bazarian JJ, Blyth B, Mookerjee S, He H, McDermott MP. Sex differences in outcome after mild traumatic brain injury. J Neurotrauma 2010;27(3):527–539
97. Preiss-Farzanegan SJ, Chapman B, Wong TM, Wu J, Bazarian JJ. The relationship between gender and postconcussion symptoms after sport-related mild traumatic brain injury. PM R 2009;1(3):245–253
98. Ponsford J, Willmott C, Rothwell A, et al. Factors influencing outcome following mild traumatic brain injury in adults. J Int Neuropsychol Soc 2000;6(5):568–579
99. Olson-Madden JH, Brenner LA, Corrigan JD, Emrick CD, Britton PC. Substance use and mild traumatic brain injury risk reduction and prevention: a novel model for treatment. Rehabil Res Pract 2012;2012:174579
100. Miller SC, Baktash SH, Webb TS, et al. Risk for addiction-related disorders following mild traumatic brain injury in a large cohort of active-duty U.S. airmen. Am J Psychiatry 2013;170(4):383–390
101. American Speech-Language Hearing Association. Traumatic brain injury in adults (practice portal). Available at: http://www.asha.org/Practice-Portal/Clinical-Topics/Traumatic-Brain-Injury-in-Adults/. Accessed September 3, 2015
102. Henry JA, Zaugg TL, Myers PJ, Schechter MA. The role of audiologic evaluation in progressive audiologic tinnitus management. Trends Amplif 2008;12(3):170–187
103. Jastreboff PJ, Jastreboff MM. Tinnitus Retraining Therapy (TRT) as a method for treatment of tinnitus and hyperacusis patients. J Am Acad Audiol 2000;11(3):162–177
104. Henry JA, Zaugg TL, Myers PJ, et al. Pilot study to develop telehealth tinnitus management for persons with and without traumatic brain injury. J Rehabil Res Dev 2012;49(7):1025–1042
105. Weightman MM, Leuty L. Vestibular assessment and intervention. In: Weightman MM, Radomski MV, Mashima PA, et al, eds. Mild Traumatic Brain Injury Rehabilitation Toolkit. Fort Sam Houston, TX: Borden Institute; 2014:9–44
106. Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. J Neurol Phys Ther 2010;34(2):87–93
107. Gottshall KR, Hoffer ME. Tracking recovery of vestibular function in individuals with blast-induced head trauma using vestibular-visual-cognitive interaction tests. J Neurol Phys Ther 2010;34(2):94–97
108. American Speech-Language Hearing Association. (Central) Auditory Processing Disorders [Technical Report]. Available at: http://www.asha.org/policy/TR2005-00043/. Accessed June 2, 2016
109. Saunders GH. Comparison with management of hearing impacts. In: Tyler C, ed. National Conference on the Management of Functional Visual Deficits in Mild Traumatic Brain Injury (mTBI). Smith-Kettlewell Eye Research Institute. San Francisco, CA: SK Press; 2013:136–141
110. Anderson S, White-Schwoch T, Choi HJ, Kraus N. Partial maintenance of auditory-based cognitive training benefits in older adults. Neuropsychologia 2014;62:286–296
111. Sweetow RW, Sabes JH. The need for and development of an adaptive Listening and Communication Enhancement (LACE) program. J Am Acad Audiol 2006;17(8):538–558
112. Moncrieff DW, Wertz D. Auditory rehabilitation for interaural asymmetry: preliminary evidence of improved dichotic listening performance following intensive training. Int J Audiol 2008;47(2):84–97
113. Anderson KL, Goldstein H. Speech perception benefits of FM and infrared devices to children with hearing aids in a typical classroom. Lang Speech Hear Serv Sch 2004;35(2):169–184
114. Boothroyd A. Hearing aid accessories for adults: the remote FM microphone. Ear Hear 2004;25(1):22–33
115. Jerger J, Chmiel R, Florin E, Pirozzolo F, Wilson N. Comparison of conventional amplification and an assistive listening device in elderly persons. Ear Hear 1996;17(6):490–504

116. Schafer EC, Thibodeau LM. Speech recognition in noise in children with cochlear implants while listening in bilateral, bimodal, and FM-system arrangements. Am J Audiol 2006;15(2):114–126
117. Johnston KN, John AB, Kreisman NV, Hall JW III, Crandell CC. Multiple benefits of personal FM system use by children with auditory processing disorder (APD). Int J Audiol 2009;48(6): 371–383
118. Sharma M, Purdy SC, Kelly AS. A randomized control trial of interventions in school-aged children with auditory processing disorders. Int J Audiol 2012;51(7):506–518
119. Saunders GH, Frederick MT, Chisolm TH, et al. Use of a frequency-modulated system for veterans with blast exposure, perceived hearing problems, and normal hearing sensitivity. Semin Hear 2014; 35(03):227–238
120. Cornis-Pop M, Mashima PA, Roth CR, et al. Guest editorial: cognitive-communication rehabilitation for combat-related mild traumatic brain injury. J Rehabil Res Dev 2012;49(7):xi–xxxii
121. Saunders GH, Echt KV. Blast exposure and dual sensory impairment: an evidence review and integrated rehabilitation approach. J Rehabil Res Dev 2012;49(7):1043–1058