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The Audiologist's Role in Assessment and Management of Mild Traumatic Brain Injuries

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THE AUDIOLOGIST'S ROLE IN ASSESSMENT AND MANAGEMENT OF MILD TRAUMATIC BRAIN INJURIES

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ABSTRACT

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Mild Traumatic Brain Injuries (mTBI) are caused by a blow to the head and have many severe consequences from amnesia and loss of consciousness to cognitive symptoms such as fatigue, pain, dizziness, light and sound sensitivity, blurry vision, and may even have vestibular symptoms like vertigo secondary to the injury. The purpose of this doctoral scholarly project is to investigate the overlap of mTBIs and vestibular disorders to understand and emphasize how audiologists can be a valuable member of a multidisciplinary team to help assess and manage patients who experience traumatic brain injuries. Audiologists can play a key role in diagnosing vestibular disorders that may otherwise be overlooked due to overlap in mTBI symptoms. Audiologists may also be the best professional to help provide treatment options such as vestibular therapy to help patients heal from a mTBI. Recommendations for future directions are included for integrating audiologists into a multidisciplinary team for managing patients with mTBIs.

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TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

LIST OF ABBREVIATIONS

AAA	American Academy of Audiology
ABR	Auditory Brainstem Response
ADP	Adaptive Protocol
ASHA	American Speech Language and Hearing Association
BPPV	Benign Proximal Positional Vertigo
BESS	Balance Error Scoring System
EVA	Enlarged Vestibular Aqueduct
ENG	Electronystagmography
ENT	Otolaryngologist/Ear Nose and Throat Doctor
CNS	Central Nervous System
cVEMP	Cervical Vestibular Evoked Myogenic Potentials
CogTest	Cognitive Sport Test
CDP	Computerized Dynamic Posturography
CT	Computed Tomography
CTP	Cochlin Tomoprotein

CN	Cranial Nerve
CRI	Concussion Resolution Index
DEH	Delayed Endolymphatic Hydrops
HAD	Hospital Anxiety and Depression Questionnaire
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
KD Test	King-Devick Oculomotor Test
MD	Meniere's Disease
MRI	Magnetic Resonance Imaging
mTBI	Mild Traumatic Injury
MCT	Motor Control Test
oVEMP	Ocular Vestibular Evoked Myogenic Potentials
PCP	Primary Care Physician
PLF	Perilymph fistula
PPPD	Persistent Postural-Perceptual Dizziness
PNS	Peripheral Nervous System
PCSS	Post-Concussion Symptom Scale
PER	Posture-Evoked Response
PM&R	Physical Medicine and Rehabilitation

PSQI	Pittsburg Sleep Quality Index
REM	Rapid Eye Movement
RPQ	Rivermead Post-Concussion Symptoms Questionnaire
SAC	Standard Assessment of Concussion
SCAT-3	Standardized Concussion Assessment Tool Version 3
SCQ	Sleep and Concussion Questionnaire
SEH	Secondary Endolymphatic Hydrops
SOT	Sensory Organization Test
SSCD	Superior Semicircular Canal Dehiscence
VOMS	Vestibular/Ocular Motor Screening
VM	Vestibular Migraine
VNG	Videonystagmography
vHIT	Video Head Impulse Test
VCR	Vestibulocollic Reflex
VOR	Vestibular Ocular Reflex
VSR	Vestibulospinal Reflex

CHAPTER I

REVIEW OF THE LITERATURE

Introduction

This review of literature covers important aspects relating to vestibular disorders secondary to mild traumatic brain injuries. Background knowledge on the anatomy and physiology of the central and peripheral auditory system is provided below along with an overview on vestibular test battery, types of vestibular disorders and head injuries in order to elucidate the prevalence between vestibular disorders secondary to mild traumatic brain injuries and how audiologists play a role in the diagnosis and assessment.

Anatomy and Physiology of the Vestibular System

The vestibular system is composed of a group of small sensory organs housed deep in the inner ear. The vestibular system is broken into two major systems: the peripheral and the central vestibular systems. Each system is bilaterally represented and uniquely contributes to balance through detection of movement and postural changes. The peripheral and central vestibular systems must coordinate with the cerebellum, cerebral cortex, brainstem, ocular muscles, and postural muscles to help maintain equilibrium and proper spatial orientation relative to gravity (Khan & Chang, 2013).

Peripheral Vestibular System

The peripheral vestibular system sits within the petrous portion of the temporal bone and consists of a bony and membranous labyrinth. The bony labyrinth contains the vestibule and semicircular canals, which are part of the vestibular system, as well as the cochlea, which is a part of the auditory system. The overall function of the bony labyrinth is to protect the organs that reside within.

Inside the bony labyrinth is the membranous labyrinth, which is composed of three semicircular ducts, cochlear duct, and the utricle and saccule. The bony labyrinth and membranous labyrinth are connected and kept in place with a thin layer of connective fibers (Kingma & Van de Berg, 2016). The semicircular ducts and cochlear duct are filled with a fluid called endolymph which is produced from the stria vascularis within the cochlea. There are three semicircular canals: anterior/superior, posterior/inferior, and lateral/horizontal that are oriented almost perpendicular to each other. Each canal is most sensitive to a specific motion of the head. When movement in the head is detected, the endolymphatic fluid is displaced within the semicircular ducts which flows into an expansion of the semicircular canals called the crista ampullaris. Inside the crista ampullaris is a gelatinous membrane called the cupula with hair cells made of rod-shaped mechanoreceptors with around 70-100 stereocilia on each end (Khan & Chang, 2013). The movement of the endolymph causes a shearing motion of the stereocilia. The stereocilia are organized from short to tall and when they bend it leads to the release of neurotransmitters that send inhibitory or excitatory movement responses to the brain. This process leads to a detection in rotational and translational, acceleration and deceleration motions. Specifically, the lateral semicircular canal detects when your head rotates left to right. The anterior semicircular canal detects when the head nods up and down. The posterior semicircular canal detects when your head tilts from shoulder to shoulder. The anterior semicircular canal opens into the utricle while it terminates at the crista ampullaris (Andreatta, 2018).

The utricle and saccule are known as otolith organs and are located at the base of the vestibular labyrinth. Inside the utricle and saccule, a sensory neuroepithelium called the macula is responsible for the detection of linear acceleration and deceleration motion (Khan & Chang, 2013). The macula in the utricle is positioned at a horizontal angle with the hair cells pointing upward to the sky. Based on this positioning, the utricle detects motion on the horizontal plane, like walking forward or backward. The macula inside the saccule is oriented at a 90-degree angle to the utricle, so the hair cells respond to vertical motion (Andreatta, 2018). The macula is similar to the crista ampullaris, however inside the macula of the utricle and saccule, there are crystal-like structures comprised of calcium carbonate chemicals called otoconia, which bend the stereocilia when there is movement of the head. Depending on the direction of the shearing, the stereocilia lead to depolarization or hyperpolarization and these signals regarding movement are sent to the brain.

Central Vestibular System

The central vestibular system is responsible for sending signals to the brain. It begins once the hair cells detect a signal, and it is transmitted through the VIIIth (Vestibulocochlear) cranial nerve to the brain to be processed. Bipolar neurons called vestibular ganglions, also known as Scarpa's ganglion, innervate the hair cells in the peripheral vestibular system (Yoo & Mihaila, 2020). The VIIIth cranial nerve is also known as the vestibulocochlear nerve which receives sensory signals from the vestibular and auditory systems. The vestibular branches of the VIIIth nerve are made up of axons from the vestibular ganglions and enter the brainstem at the pontomedullary junction. There are medial and lateral tracts that extend to the pons, while other nerve fibers travel to the flocculonodular lobe in the cerebellum (Khan & Chang, 2013; Yoo & Mihaila, 2020). Vestibular nuclei in the pons continue to extend to the spinal cord down the lateral vestibulospinal tract where they synapse with the ventral grey horn and innervate different muscles to maintain posture. In the medial vestibulospinal tract, the nuclei synapse with the medial grey horn to innervate the face and neck muscles to maintain head stability (Yoo & Mihaila, 2020).

Afferent fibers from the vestibular ganglion innervate in the flocculonodular lobe of the cerebellum. Efferent fibers in the cerebellum are projected to cranial nerves III (Oculomotor), IV (Trochlear), and VI (Abducens) which regulate eye movement. Together vestibular ganglion nerves and the other cranial nerves control eye movement leading to better balance and control.

Vestibular nuclei enter the thalamus before projecting further to the cerebral cortex. The cerebral cortex processes other proprioception information from different areas of the body as well as visual cues. Both the thalamus and cerebral cortex are involved in perceived body orientation, spatial awareness, and overall balance.

As mentioned above, the vestibular nuclei work with other cranial nerves and innervate different parts of the brain to maintain balance, spatial awareness, and posture. There are three different reflexes that contribute to the success of these functions. The vestibulo-ocular reflex (VOR) coordinates eye movements and stabilizes vision during head rotation by maintaining a steady balance through the peripheral organs that sense motion like the saccule, utricle, and semicircular canals. The central nervous system processes the sensory information and relays the information through motor outputs, specifically, eye muscles. The VOR is activated when the head is turned in one direction; the eye muscles move in the opposite direction to maintain balance. For example, when the head moves to the left, the eyes will move to the right and vice versa. The vestibulo-spinal reflex (VSR) integrates all information from the peripheral nervous system and other systems in the body for posture and balance. Lastly, the vestibulo-collic reflex

(VCR) stabilizes the neck muscles for head movement (Khan & Chang, 2013). Together all the systems and reflexes are necessary to maintain balance, spatial orientation, and posture.

Lastly, in order for all of this to be possible there needs to be a source of blood supply. The labyrinthine artery branches from the anterior inferior cerebellar arteries that brings blood into the peripheral vestibular system. The labyrinthine artery separates into a vestibular artery, which supplies the blood supply to the labyrinth, part of the semicircular canals, utricle and saccule and the cochlear artery which supplies blood to the cochlea and the other part of the semicircular canals. In the central nervous system, blood is circulated from posterior inferior cerebellar arteries to the anterior inferior cerebellar arteries (Yoo & Mihaila, 2020).

Central and Peripheral Nervous System Anatomy/Physiology

The body has a central nervous system (CNS) and a peripheral nervous system (PNS). The central nervous system is comprised of the brain, brainstem, and spinal cord, while the peripheral nervous system includes the nerves that transfer information through the body. The central nervous system analyzes and integrates motor and sensory information. The brain sits within the protective skull bone and has three protective layers known as meninges surrounding it. The outermost layer is the dura mater, followed by the arachnoid mater, and innermost layer, the pia mater. Cerebral spinal fluid is a protective fluid that sits in between the arachnoid layer and pia mater. This space is known as the subarachnoid space (Snell, 2010). The brain tissue itself is composed of white and grey matter. Grey matter is made up by groups of cell bodies, and the white matter consists of bundles of axons that transfer information between the nuclei (Andreatta, 2018).

The brain is a very complex structure in the human body that controls every thought and action. The brain is medically known as the cerebrum, which can be split into two symmetrical, left and right regions, called cerebral hemispheres. The hemispheres are connected by a structure in the center of the brain called the corpus callosum, which is made up of white matter. The left hemisphere is primarily responsible for movement and sensation on the right side of the body, as well as logic and language. The right hemisphere is responsible for the movement and sensation on the left side of the body, processing acoustic inputs, and intuitive functions such as memory, creativity, and emotion. Each hemisphere in the cerebrum is split into four lobes: frontal, parietal, temporal, and occipital. Each lobe has different unique functions. The frontal lobe has the primary motor cortex, premotor and supplementary motor cortex. The primary motor cortex is an integrative hub for movement from the cerebellum. The pre-motor area is responsible for planning action. Broca's area is also within the frontal lobe, which is an area concerned with speech production. Overall, some functions of the frontal lobe are attention, concentration, self-monitoring, organization, awareness, expressive language, problem-solving, judgment, and personality. Injury to the frontal lobe may lead to impulsive behavior and difficulty recalling events. The parietal lobe's function is spatial perception, sense of touch, and visual perception. A major grouping in the parietal lobe is the primary somatosensory cortex which is the receptive site for sensory input related to touch, proprioception, thermal sensations, and pain (Andreatta, 2018). Injury in this lobe may affect one or more of the five senses. The occipital lobe's primary function is vision. Fifty percent of brain pathways are dedicated to vision, therefore, injury to the occipital lobe will likely result in visual impairment, difficulty perceiving characteristics of objects, like shape, color, or size (Ventura et al., 2014). Lastly, the temporal lobe's functions are memory, comprehending language, sequencing, and hearing. Within the temporal lobe is Wernicke's area which is associated with language comprehension and the primary auditory cortex that processes and perceives auditory input. Injury to this lobe may lead to communication or memory difficulties.

Another important region of the brain is the limbic system, which is a group of structures between the central cortex and hypothalamus, including the amygdala, hippocampus, cingulate gyrus, thalamus, and hypothalamus (Andreatta, 2018). The amygdala is the primary structure associated with emotional function. The hippocampal region is important for learning and memory. The cingulate gyrus is another part of the limbic system that connects emotion and cognition. It may also play a role in attention, motor control, and vocalization. Together these structures work together to regulate emotion and may play a role in learning, memory, and some automatic processes.

The diencephalon sits in between the two hemispheres and is made up of two structures: the thalamus and hypothalamus. The thalamus and hypothalamus are structures, made up of grey matter that are also thought to also be a part of the limbic system. The thalamus is a relay center for all senses, except for olfaction. It is also responsible for motor-related circuits that help humans learn movements, respond with appropriate and smooth motion based on the situation (Andreatta, 2018). Lastly, the thalamus plays a role in cognition, psychological behavior, and metabolic control. The hypothalamus is responsible for automatic functions that maintain homeostasis.

The cerebellum sits beneath the cerebrum and controls balance, movement, and coordination. The cerebellum connects to the brainstem. The brainstem has three parts: the midbrain, medulla, and pons. The pons control involuntary functions essential to survival such as breathing, heart rate, sleep cycles, and consciousness. The midbrain is the uppermost segment of the brainstem, associated with motor control functions in the cerebellum and cranial nerves III

(Oculomotor) and IV (Trochlear) for the movement of the eyes. The medulla is innervated by cranial nerves IX (Glossopharyngeal), X (Vagus), XI (Accessory), and XII (Hypoglossal), therefore some individual functions are related to hearing, balance, swallowing, vocal production, and movement of the tongue. The pons are primarily responsible for the refinement of coordinated movements and houses several non-cranial nerve nuclei like the superior olivary complex which is related to sound localization, attention, and respiratory control.

The peripheral nervous system includes any nerves outside of the central nervous system. The VIIIth cranial nerve is the primary nerve that will be mentioned regularly. In the auditory pathway, after the sensory cells within the cochlea or vestibule detect a signal, cranial nerve VIII is activated. It sends the signal up the pons and enters the cochlear nucleus in the medulla. The cochlear nucleus maintains tonotopic organization from the cochlea. Next, it travels to the superior olivary complex where sound can be received from both ears to aid in localization. The lateral lemniscus is the next stop in the midbrain as well as the inferior colliculus, which integrates auditory information. Auditory input terminates in the auditory cortex within the temporal lobe where it is perceived. This pathway is vital to understand and differentiate between peripheral or central trauma.

Disorders of the Central and Peripheral Vestibular System

Traumatic Brain Injury

Traumatic brain injury (TBI) is a term used when there is a disruption in the normal function of the brain and causes injury to any part of the central system. Many factors can cause this such as a bump to the head, the head suddenly being jerked, or something pierces the skull and enters the brain tissue. All these factors lead to different types of injuries: brain contusions, concussions, and penetrating injuries. A brain contusion is bruising in the brain that results from mild bleeding. Concussions are when the brain is suddenly accelerated or decelerated. Commonly, concussions are often from an impact to the head or a result from "whiplash" which is a sudden jerk motion to the head and neck (Silverberg et al., 2020). Axons are fibers within the brain susceptible to injury during a TBI. Diffuse axonal injuries are a severe TBI that occurs when the brain shifts positions with traumatic force intense enough to shear the long connection fibers in the brain. Penetrating injuries can lead to thromboses, which are blood clots in the brain; hemorrhages, which are areas of bleeding in the brain; and/or ischemia, which is insufficient blood supply to the brain.

The term concussion is the oldest term and comes from the Latin term "concuss" which means to shake violently. While this has been around for many years, it wasn't until the 10th Century A.D. that a Persian physician made a distinction between traumatic brain injuries and concussion (Mullally, 2017). To this day, concussion definition is still not clearly defined leading to confusion between patients, support partners, and medical professionals. A concussion is often used interchangeably with a "mild traumatic brain injury." With that being said, concussion is the more common term in the sports medicine community and mTBI is used in the medical community (Apps & Walter, 2012). For the purpose of this paper, mTBI will be the referred term.

Physiology of Mild Traumatic Brain Injuries

When a mTBI occurs, many physiological changes occur over the next couple of hours post-impact, though there is not one agreed upon theory as to what occurs to the brain after impact. Mullally (2017) described the pathophysiological theory for mTBI; that after impact there is a sudden release of neurotransmitters, like glutamate, causing a large release of potassium out of cells and calcium into the cell. This process is vital to homeostasis in the cell and to create adenosine triphosphate for energy. This sudden change in chemical imbalance can cause a transient hypermetabolic glycolytic state which reduces blood flow and lactate builds up. If calcium remains in the cell too long, it can cause axonal and cell death, which impacts the communication between cells, can damage blood flow and result in cortical spreading depression. From a symptomatic standpoint, the damage can cause migraines, seizures, and ischemia (Mullally, 2017). Adams et al. (1989) developed a theory around axonal diffusal injury which can occur in severe TBI cases. Axonal diffusal injury is when axon connections have been sheared. This leads to an influx of calcium, which can cause microtubule disassembly and neurofilament compaction (Blennow et al., 2012). Diffusal axonal injury is considered a leading theory to explain the causes of lasting cognitive, emotional, and physical symptoms post-mTBI (Tjarks et al., 2013).

Tau pathology and tangle formation is another theory to support the pathophysiology of a mTBI. Tau is a normal axonal protein that binds to microtubules to promote stability in the brain. If the tau protein becomes tangled it can cause a disassembly of microtubules and axonal transport which compromise neural function (Blennow et al., 2012). Tau pathology and tangle formation are also commonly found in patients with Alzheimer’s Disease.

Other possible pathogenic mTBI theories include microglial activation, regenerative phenomenon, TDP-43 pathology, and lack of alpha-synuclein. Atrophy in the brain has been recorded through imaging, though the etiology is unknown. It affects both grey and white matter regions, but it is unknown whether the atrophy is due to the mTBI itself or the severity. Volume loss in the brain can be found up to years later, following mTBI and is not due to normal aging, but is likely progressive and a risk factor for dementia (Cole et al., 2018). These theories may contribute to the explanation of how the brain responds to a mTBI, but there is limited research on the efficacy of these theories and are beyond the scope of this review.

Mild Traumatic Brain Injury

mTBI can be difficult to diagnose objectively and there is much controversy on how to evaluate mTBI. Imaging studies such as a computed tomography (CT) scan and magnetic resonance imaging (MRI) are often reported as normal because they are not sensitive enough to detect the subtle changes in brain composition to diagnose mTBIs. Neuroimaging is only recommended for patients with specific “red flag” symptoms like a penetrating injury, comorbidities, vomiting, agitation, slow responses, amnesia, or above the age of 65 (Silverberg et al., 2020). Due to lack of objective evidence to diagnose mTBIs, clinicians must rely on common clinical symptoms. Unfortunately, there is a wide range of accepted diagnostic criteria (Silverberg et al., 2020). The American Congress of Rehabilitation Medicine diagnostic criteria include loss of consciousness and impaired mental state, such as being disoriented, confused or loss of memory. The American Academy of Neurology includes loss of consciousness and mental state along with other subjective symptoms like headache and dizziness (Ruff et al., 2009). The most common symptoms of mTBI are headaches and dizziness, but it is not uncommon to have other symptoms such as, light and loud sound sensitivity, fatigue, sleep disturbances, and nausea. Sleep disturbances include increased awakenings, less rapid eye movement (REM), and hypersomnia. Sleep may also be connected to the ability to regulate emotion which can also occur after a mTBI (Mantua et al., 2017).

The presence of these symptoms can support a diagnosis but are not recommended for sole diagnosis of mTBI (Silverberg et al., 2020), rather a test battery of different tests should be utilized. The Centers for Disease Control and Prevention (2015) separate signs and symptoms into four categories: physical, cognitive, emotional, and sleep-related difficulties.

Mild Traumatic Brain Injury Diagnosis

There are over 25 grading systems in literature to assess the severity of mTBI (Apps & Walter, 2012). According to the Colorado Medical Society and the American Academy of Neurology, there are three severity classifications for mTBI. A grade one mTBI is defined by no loss of consciousness, but confusion without amnesia. The American Academy of Neurology also includes symptoms that last less than 15 minutes. If the symptoms persist past 15 minutes with no loss of consciousness, but confusion with amnesia, it is classified as a grade two mTBI. A grade three mTBI has any loss of consciousness, confusion, and amnesia. Only 10% of mTBIs result in loss of consciousness, so a grade three is much less common (Apps & Walter, 2012). A grade three mTBI would likely result in an immediate medical evaluation including imaging scans to rule out brain hemorrhages. Neck pain and neurological signs should also prompt a referral to the emergency department. These are general guidelines to try to the qualify severity of mTBI, but there is a large grey area as it varies between each individual. It is not uncommon for coaches or bystanders to witness a potentially concussive event in which impact to the head results in acute or chronic symptoms, but in some, asymptomatic or “subclinical” symptoms occur. Severity of mTBIs range based on the type of impact and the individual’s response, therefore grading scales are not commonly used anymore (Apps & Walter, 2012). After mTBI, persistent cognitive, physiological, emotional, and sleep-related symptoms may occur. Many symptoms will resolve in one to four weeks, but if symptoms persist beyond three months it is referred to as post-concussive syndrome which may occur in up to 15% of cases (Marshall et al., 2012).

Recommended evaluations include a clinical exam, postural assessment, and neurocognitive testing, which includes concentration, academics, processing speed, memory, intellectual, and emotional functioning, alongside a self-reported symptom checklist. The goal of the assessment is to establish whether a mTBI is present and the severity, to help monitor healing progress and determine management (Van Kampen et al., 2006). The most common comprehensive assessments for individuals with a potential head injury are the Standard Concussion Assessment Tool (SCAT-3), Post-Concussion Symptom Scale (PCSS), the Rivermead Post-Concussion Symptoms Questionnaire (RPQ), Standard Assessment of Concussion (SAC), the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), the Concussion Resolution Index (CRI), Cognitive Sport test (CogSport), and King-Devick (KD) tests (Dessy et al., 2017). It is important for the medical team to be thorough and skeptical of the patients' responses, especially when working with athletes. Athletes that potentially have a mTBI may choose not to disclose all their symptoms because they do not want to be taken out of their sport. They may also fear criticism from their parents, coaches, or teammates (Apps & Walter, 2012). Subtle signs to pay attention to are forgetfulness, coordination, behavior changes, and appearing dazed.

The Glasgow Coma Scale for consciousness evaluation rates patients in eye opening, verbal responses, and motor responses. Patients are classified with a mild, moderate or severe injury. It can be a quick and reliable screening test but does not account for severity or persistence of symptoms (Apps & Walter, 2012).

The Rivermead Post-Concussion Symptoms Questionnaire (RPQ) is a questionnaire utilized to analyze symptoms to help diagnose a mTBI and the severity. Sixteen common mTBI symptoms are rated on a Likert Scale of 0-4. Multiple clinical studies reported differences in categorical results and unidimensionality (Eyres et al., 2005; Lannsjö et al., 2011). This means that the 16 symptoms on the RPQ do not tap into the same validity constructs and cannot be summated into a single score, therefore, RPQ is used less commonly than other mTBI tests and should be taken with serious consideration to diagnose mTBI and severity.

The Post-Concussion Symptom Scale (PCSS) is a self-reported questionnaire where the patient rates every symptom on a 1-6 Likert scale based on severity. The PCSS is endorsed by the National Athletic Trainer's Association (Dessy et al., 2017) and recommended by the American Academy of Neurology. Since it is a self-reported questionnaire, it is a good resource that accounts for each individual's mTBI symptoms; however, due to variable results, the specificity and sensitivity rates are not high, so the PCSS should be used as a supplement to other questionnaires and assessments.

The Standardized Assessment of Concussion (SAC) is a sideline test that assesses the effects of a mTBI on recall, concentration, and orientation. This test focuses on the neurocognitive skills affected by mTBI. The SAC has a strong sensitivity and specificity but should not be used for monitoring progress for return-to-play protocol, because many patients return to baseline within 48 hours of taking the test (Dessy et al., 2017). Another limitation is the SAC focuses primarily on neurocognition so once again, the test should be used with other diagnostic questionnaires and assessments.

The Cognitive Sport Test (CogSport) is a neurocognitive test that assesses attention, decision-making, reaction time, matching, and working memory. The test also has high sensitivity and specificity (Dessy et al., 2017). Diagnostic assessments of the CogSport Test can be given with the baseline method or normative method (Louey et al., 2014). The baseline method is when the patient takes the test before and after they have a possible mTBI to compare results. Baseline data is more sensitive to identify mTBI and often used as a pre- and post-test for athletes in high-risk sports for mTBI. The normative method is completed when no baseline data is available, so results are compared against scores that are indicative of abnormal cognitive function.

The Balance Error Scoring System (BESS) is used to assess balance and postural stability. For clinical application, BESS testing in young children will have lower scores because they have not developed correct posture, therefore, interclass correlation coefficients are accepted to measure reliability. BESS provides some objective balance information during a mTBI evaluation which is very useful for a mTBI diagnosis, but there is limited data to support the use of this test for monitoring recovery.

The Sport Concussion Awareness Training Tool Version 3 (SCAT-3) is a sideline test that was developed for children aged 13 and older. It is a comprehensive test that assess mTBI symptoms with the PCSS, Glasgow Coma Scale for consciousness evaluation, Maddocks Scores for orientation and time, the SAC for cognition, and neurological symptoms, neck examination, and a modified BESS for balance/coordination assessment. The SCAT-3 utilizes a variety of other tests to form a sensitive, valid, and reliable test battery, therefore making it the most widely used sideline test. Baseline testing is optional and does not greatly affect the validity or reliability, however, it may be useful for return to play protocols.

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is an online neurocognitive computer assessment test that measures verbal memory, visual memory, reaction time, and visual-motor speed. The test should be administered prior to action and post-injury. This test is commonly given in an athletic setting. A couple of years later, Schatz and Ferris (2013) found that repeated exposure to the ImPACT test does not result in the practice effect or reaction time. Dessy et al. (2017) reported the ImPACT has a high sensitivity and specificity, though some athletes may not be truthful when taking the pre-test in hopes of getting back to play quicker because their scores are not as high. There is also a pediatric version of this test.

The Concussion Resolution Index (CRI) is an online neurocognitive and neurobehavioral assessment tool that analyzes visual recognition, information processing, and reaction time. The assessment is given to help diagnose mTBI and is given over a period of time to track the symptoms and date of resolution. This tool has a high sensitivity. The test assessment is supposed to establish a baseline and monitor the symptoms to assist with return to play decisions (Erlanger et al., 2003).

The King-Devick (KD) Oculomotor Test is unique from many other mTBI tests because it does not look at symptoms, but rather assesses neuronal injury that can result in poor oculomotor function. Visual-motor deficits like abnormal saccades, smooth pursuit, fixation, and photosensitivity are estimated to be present to some degree in 65 - 90% of patients who have experienced some form of mTBI (Heitger et al., 2009). This test is recommended to supplement other tests mentioned above because it is the only test to assess oculomotor function (Dessy et al., 2017).

Vestibular/Ocular Motor Screening (VOMS) assesses vestibular and oculomotor functions with smooth pursuit, horizontal and vertical saccades, convergence, horizontal vestibular ocular reflex (VOR), and visual motion sensitivity (Mucha et al., 2014). mTBI may result in impaired vision and interfere with the VOR reflex, so this test is useful to measure those functions. The test is also used for patients with vestibular systems disorders and can be used to measure vestibular functions not measured with the BESS and the KD Test with good reliability and validity (Yorke et al., 2017).

Sleep disturbances are a common symptom post mTBI. The Sleep and Concussion Questionnaire (SCQ) was developed to help determine the severity of the mTBI and how much it impacts daily activities. Toccalino et al. (2021) compared the SCQ to polysomnography and self-reported measures which confirmed a meaningful correlation, supporting the convergent validity. Other sleep questionnaires like the Pittsburg Sleep Questionnaire (PSQI) were not originally constructed to be used with mTBI, however, a study by T. Y. Huang et al. (2015) discovered that sleep is commonly affected within the first month of the mTBI. While the PSQI is a valid and reliable test, there is limited research on the validity in patients with mTBI. It may be used however to see how much sleep is impacting the patient and their quality of life.

The Hospital Anxiety and Depression (HAD) Questionnaire is sometimes used to assess emotional disturbances after a mTBI. This test is reliable for assessing emotional distress in mTBI patients (Whelan-Goodinson et al., 2009). Clinicians should display caution when using this tool for diagnosis, but rather utilize it for determining a referral to a psychiatrist or psychologist for a full evaluation and formal evaluation.

Lastly, another assessment method, though not proven as reliable and valid, is to track symptoms on a self-reported Likert scale. It is a quick and easy way to monitor progress. Some considerations when assessing mTBI symptoms is to consider functional limitations due to symptoms to help understand the severity of the diagnosis. Limitations may be organized into three subgroups: daily activities (i.e., personal care), major activities (i.e., work, school, taking care of the house), and leisure activities to track symptoms relating to specific activities.

There are many other questionnaires and assessments available, however, based on this research, there is currently no individual mTBI assessment that has the sensitivity to use in isolation. Rather, it is recommended to utilize multiple assessments that analyze neurocognitive functioning, postural control, and self-reported symptoms in order to increase sensitivity to a clinically acceptable level. The use of multiple checklists, screening, and assessment tools such as the SCAT-3 with the vestibular/oculomotor screening are recommended to help diagnose and monitor mTBIs progress. A summary of the tests is included in Table 1.

Table 1

Summary of Mild Traumatic Brain Injury Assessment Tools

Assessment Tool	What is Measured
Glasgow Coma Scale	Evaluation of consciousness including eye opening, verbal, and motor responses
Post-Concussion Symptom Scale (PCSS)	Questionnaire that the patient reports symptoms and severity on a 1-6 scale.
Standard Assessment of Concussion (SAC)	A sideline test that analyzes neurocognitive skills such as memory, concentration, and orientation.
Rivermead Post-Concussion Symptoms Questionnaire (RPQ)	Self-reported scale measuring severity of symptoms after mTBI.
Cognitive Sport Test (CogTest)	Neurocognitive assessment that analyzes attention, decision-making, reaction time, matching, and working memory.
Standardized Concussion Assessment Tool (SCAT-3)	Standardized sideline to assess mTBI. This test utilizes the Maddocks Score for orientation and time, Glasgow Coma Scale, PCSS, SAC, and modified BESS.
Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)	Online neurocognitive assessment measuring verbal memory, visual memory, reaction time, and visual-motor speed.
Concussion Resolution Index (CRI)	Online neurocognitive and neurobehavioral assessment measuring visual recognition, information processing, and reaction time.
King-Devick Oculomotor Test (KD Test)	Assess neuronal injury through oculomotor function such as saccades, smooth pursuit, fixation, photosensitivity.
Vestibular/Ocular Motor Screening (VOMS)	Assesses vestibular and ocular functions with smooth pursuit, horizontal and vertical saccades, convergence, horizontal VOR, and visual motion sensitivity.
Balance Error Scoring System (BESS)	Test used to assess balance and postural stability.
Sleep and Concussion Questionnaire (SCQ)	Questionnaire developed to analyze how much the mTBI is affecting sleep quality.
Hospital Anxiety and Depression Questionnaire (HADs)	Self-assessment tool used to measure the severity of anxiety and depression a person is experiencing. This test is not developed for mTBI but used to see how mTBI are affecting anxiety levels.

Mild Traumatic Brain Injury Management

In addition to the lack of consensus among scientists and medical professionals for mTBI etiology and diagnostic assessments, management for mTBI is also widely variable. Management of mTBI addresses the symptoms from the mTBI, but likely does not target the underlying etiology (Wing et al., 2017).

Within the first 24 hours, observation is vital. While it used to be standard practice, athletes that had symptoms disappear in 15 minutes could return to play within the same day. That is no longer recommended, and athletes should sit out for at least 24 hours. Animal models have demonstrated an increased risk for another mTBI is greatest between seven to ten days (Brown & Camarinos, 2019). Repeat mTBI injuries have more severe consequences, can lead to slower recovery times and worse impairments.

Patients who need immediate attention after mTBI may be admitted to the hospital for close observation, pain management, surgery, and/or hydration. Most patients with mTBI can heal and recover at home. Patients with mTBI are recommended to limit physical and cognitive activity and reduce exposure to aggravating stimuli. Chronic symptoms should be managed individually. One of the most common managements is cognitive and physical rest. Cognitive rest is avoiding activities that require concentration and attention, including limiting schoolwork, job-related work, cellphone usage, computer usage, and television time. Physical rest is avoiding any physical activity that aggravates symptoms like exercise and household chores. Relative rest is recommended for at least 24-48 hours. Complete rest like lying in a dark room with no stimuli has not been proven to accelerate recovery (Silverberg et al., 2020) and may even slow down recovery time (Carter et al., 2021). Sleeping is a part of rest. Sleep is important for neuroplasticity, memory, and learning; therefore, it can also be critical for mTBI recovery. Forty to sixty percent of patients report insomnia after mTBI (Toccalino et al., 2021). Previously, sleep has been debated because there was a fear of brain swelling during sleep, which since, has been disproven. Other forms of management depend on symptoms. Socially, it is important to remain engaged, but avoiding stimulating environments like movie theaters, sporting events, performing art venues, and even restaurants that are busy can eliminate trigger symptoms. At home and work, give breaks to relax eyes and reduce stress. Wearing sunglasses for photophobia, earplugs for decreased sound intolerance, and some medications may help with pain or sleep if approved by a doctor. Specifically anti-inflammatory drugs may be recommended.

Physical activity has many benefits that promote a healthier lifestyle and can improve physical and mental health. Mild exercise has been recently studied to see if it can speed up recovery time. Recovery time was compared for an aerobic exercise group and a stretching group in a randomized control trial (Leddy et al., 2019). The aerobic exercise group recovered faster than the stretching group, indicating that exercise within the first week after a sport-related mTBI may speed up recovery. A systematic review and meta-analysis review was conducted by Carter et al. (2021) to look at the effects of physical exercise on post-mTBI scores. Every physical activity group analyzed saw an improvement in symptoms with no reports of adverse effects in any of the 23 studies analyzed. Carter et al. (2021) also analyzed the type of physical activity, intensity, and duration length. All active rehabilitation groups had positive results, but subthreshold activity had the greatest effect on symptoms compared to a multimodal approach which included aerobic training, coordination training, visualization training, and home-based programs. Physical therapists and athletic trainers would most likely be the professionals to deliver active rehabilitation. A study by Dobney et al. (2018) investigated the best time to begin active recovery. The participants who began between two to three weeks post mTBI demonstrated the most improvement over the groups of participants that began before two weeks and after four weeks post mTBI. With that being said, there is growing evidence to support mild exercise to help improve recovery time in patients with mTBIs, but more research is needed to understand when to begin active recovery as well as the intensity and duration of exercise necessary to speed up the recovery. Overall, active recovery may be beneficial and encouraged as management on a case-to-case basis.

The variability in recovery time is highly dependent on each patient and the severity of the injury. Sometimes patients recover in a couple of days, while it takes others a couple of months. Occasionally, there are some patients who have poor long-term outcomes. Since there is no universal recovery pattern, it is important to consider other risk factors that may contribute to the recovery process, such as history of mTBI, severity, comorbid conditions, age, loss of consciousness, and medications. After resolution of symptoms, slow transitions back into school, work, and athletic-related activities are still recommended to avoid reinjury (Scorza et al., 2012). Management for mTBIs is highly variable and dependent on symptoms, but the most widely accepted management is still cognitive rest, active rest, medications, and intervention for specific symptoms.

Vestibular Introduction

There are many different vestibular disorders that have overlapping symptoms with mTBIs; the most common is dizziness. It is important to differentiate between some common terms that are all associated with dizziness. Imbalance is the umbrella term for disequilibrium, dizziness, and vertigo. Disequilibrium is a term for unsteadiness, often accompanied with spatial disorientation, while dizziness is a sensation of light headedness and unsteadiness but has no rotational spinning. Vertigo is the perception of movement, often in a spinning or rotational direction. Many patients struggle differentiating between these terms, so professionals are encouraged to ask further questions to ensure the correct symptom is being recorded. Based on the vocabulary, it may impact the chosen vestibular test battery because different symptoms will match different disorders. A comprehensive vestibular test battery is necessary to diagnose the disorder and will be discussed in this next section, followed by a section on the different disorders' symptoms, assessment, and management.

Vestibular Test Battery

Vestibular disorders have a large range of symptoms and can be challenging to differentially diagnose. The first step is to collect a detailed case history followed by tests to differentiate between a central or peripheral site of lesion.

Central vestibular disorders are often caused by lesions, multiple sclerosis, and/or tissue death (Brandt & Dieterich, 2017). Central disorders are more likely to have chronic, slow onset of imbalance, dizziness, lightheadedness while standing or walking and have slow, continuous subjective vertigo. Patients with central disorders are more likely to continue daily activities with discomfort. Vertigo independent of location will always result in sudden asymmetrical neural activity.

Peripheral disorders are more commonly episodic and have sudden onset of vertigo, dizziness, and/or imbalance. Peripheral paroxysmal spontaneous events are shorter than 24 hours and head movements provoke symptoms that should subside in less than two minutes; however, continuous head movement may provoke symptoms for days. Patients with peripheral disorders are often able to identify the first episode they experienced, and each episode is completely debilitating. Peripheral disorders are also more likely to have auditory involvement. Some patients will have clear symptoms from either central or peripheral pathologies, while others will have a combination of symptoms.

Observation of nystagmus is key to differential diagnosis between the central and peripheral system. Peripheral origin often has a direction-fixed or horizontal nystagmus, while central origin will have a direction-changing nystagmus that is more likely to be enhanced with a fixation present. Peripheral origin will have abnormal VOR with caloric testing or head impulse testing and the nystagmus is more likely to be exaggerated with a horizontal headshake, while central origin will have a vertical nystagmus present post headshake. Central origin will also most likely have an abnormal performance of saccades and smooth pursuit. These differences are shown in Table 2. While a good portion of vestibular disorders share an overlap in symptoms, the most common central disorders that will be discussed include vestibular migraine, and Persistent Postural Perceptual Dizziness. The peripheral disorders that will be discussed are benign positional paroxysmal vertigo, enlarged vestibular aqueduct, labyrinthine concussion, Meniere's Disease, post-traumatic endolymphatic hydrops, perilymph fistula, and superior semicircular canal dehiscence.

Following a detailed case history to help differentiate central and peripheral pathologies, asking some other questions about if noise or pressure induces vertigo and length of episode may also help differentiate between disorders. Around 60% of vestibular disorders can be identified through detailed case history (Babu et al., 2019). Understanding the onset of symptoms, severity, and duration are important questions to ask. There are a variety of tests that audiologists utilize to help diagnose a disorder. It is important to understand what each test is measuring and what normal and abnormal results indicate in the following sections. Some common vestibular tests are Electronystagmography (ENG)/Videonystagmography (VNG), positional testing (Dix-

Hallpike), Computerized Dynamic Posturography (CDP), Vestibular Evoked Myogenic Potentials (VEMP) testing, Video Head Impulse Testing (vHIT), and rotary chair.

Table 2

Differentiating between Central and Peripheral Pathologies

Peripheral Disorders	Central and Peripheral Disorders	Central Disorders
Short duration vertigo episodes unless provoked by constant head movement	Sudden onset of dizziness, imbalance, vertigo	Chronic continuous, slow objective vertigo
More likely to have auditory involvement		Slow onset of imbalance, affecting walking and standing, syncope
Direction-fixed nystagmus or horizontal nystagmus		Direction-changing nystagmus enhanced with fixation present
Suppressed by vision		No vision suppression
No cranial nerve involvement		Other cranial nerve involvement
Horizontal nystagmus post headshake		Vertical nystagmus post headshake and abnormal VOR for saccade and smooth pursuit testing

The most common vestibular assessment is a set of tests measured with the use of electrodes to measure oculomotor function called ENG or VNG/infrared video goggle tests. Both ENG and VNG evaluate the inner ear by recording eye movement in light and dark settings. ENG records eye movement through small electrodes placed near the eye, while VNG uses a video camera mounted inside eye goggles. Eye movements cause deflection in the ENG recordings (Babu et al., 2019). During an ENG or VNG, there are specific subtests that evaluate the peripheral vs. central vestibular function. Vestibular function tests include the gaze test, saccades test, optokinetic test, smooth pursuit test, positional testing (Dix-Hallpike maneuver), and calorics. Jacobson et al., (2020) described the following central ENG/VNG tests: saccades, gaze testing, smooth pursuit tracking test, and optokinetic test. The saccades test is used to calibrate the equipment and test for abnormalities. The patient will track a random target on a screen that moves on a horizontal plane left and right as well as a vertical plane, up and down. Abnormal results include overshooting or undershooting the target. The gaze test is performed by recording the patient's eye movement while looking 30 degrees above, below, left, and right for at least 30 seconds. Spontaneous nystagmus will occur if there is a unilateral vestibular dysfunction. During the smooth pursuit tracking test, the patients also look at a target that moves left to right on a horizontal plane and up and down on a vertical plane, but the target moves in a smooth motion. The patient should be able to track the moving target in a smooth, symmetrical motion. Abnormal results include the inability for the eye "catch up" to the target. Lastly, the optokinetic test uses a series of targets moving left or right on a horizontal plane inducing a nystagmus, characterized as fast and slow phases on the ENG/VNG. Similar to smooth pursuit testing, normal individuals should catch the targets and simulate a nystagmus, while abnormal results reflect an atypical fast or slow phase velocity (Babu et al., 2019). Each test should be completed for different eye movement and direction and results should be analyzed for oculomotor asymmetry.

Caloric testing is often part of the ENG/VNG test battery and is the only test that allows each ear to be stimulated separately and can be invaluable to diagnosing Meniere's disease, labyrinthitis, and other peripheral disorders (Babu et al., 2019). Cool water is irrigated into the ear slightly below body temperature, followed by a second part of the test where warm water is irrigated into the ear slightly above body temperature. This test can also be completed with temperature-controlled air. Normal results with cold water will generate a nystagmus response beating opposite from the ear stimulated, while warm stimuli, will result in a nystagmus that will beat in the same direction as the ear stimulated (Jacobson et al., 2020). Abnormal results include spontaneous, hyperactive nystagmus, directional preponderance, inability to suppress nystagmus with fixation, or unilateral weakness (Jacobson et al., 2020). This test can also be completed with temperature-controlled air blown into the ear instead of water.

The headshake test is performed in a seated position, while the head facing down at 30 degrees and shaken side to side for about 20 seconds with infrared goggles on. Normal results demonstrate equal responses on both sides without a post-rotary nystagmus. If a nystagmus occurs, it is likely due to a unilateral vestibular hypofunction (Babu et al., 2019).

The Dix-Hallpike maneuver is a positional test that assesses the semicircular canals. The Dix-Hallpike maneuver can be completed with or without infrared goggles, therefore it can also be included in the VNG/ENG test battery. The test requires a patient to start sitting and the professional will rapidly lay the patient down while the head is moved to a 45-degree angle hanging off the table. An objective positive result is if a rotational nystagmus is observed in the ear affected, while a subjective test includes patients reporting vertigo from the test (Babu et al., 2019).

Computerized Dynamic Posturography (CDP) is used to evaluate contributions of visual, vestibular, and sensory systems for balance. The patient is tested with eyes open and closed while standing on a still or moving platform. Typically, CDP has four main functional protocols: the posture-evoked response (PER), the motor control test (MCT), the adaptive protocol (ADP), and the sensory organization test (SOT) (Babu et al., 2019). The SOT test will evaluate the patient’s ability to remain still in six conditions. The testing conditions include eyes open, closed, and four conditions where the support force plate sensory surfaces or the visual walls will sway. There is a sequence of difficulties between the first and the last test. In the first test, the eyes are open and the patient stands still, the last test the eyes are open and the ground and visual reference sway (Jacobson et al., 2020). The second test is the MCT test in which a patient will stand on a force plate that will move forward and backward at a slow, medium, and fast speed. This test evaluates the bodies' ability to compensate for translational movement at varying velocities. Normal results include weight symmetry, active force strength, and latency based on age (Babu et al., 2019). Lastly, the ADP test exposes the patient to five, identical toes up or toes down rotations. Typically, the patient will get better by the fifth trial, if the patient does not respond quicker by the last trial the results are likely abnormal. Occasionally a fourth test is completed called the PER. This test is similar to the ADP, but the PER test exposes the patient to a random set of toes up or down movements at a high velocity. Patients without a pathology will respond quicker than some of the initial trials. Abnormal results will present in patients who have exaggerated responses to every trial (Babu et al., 2019). The collection of all four of these tests will give the audiologist an idea of what systems are impacted and what disorders could contribute to those results.

Vestibular Evoked Myogenic Potential (VEMP) evaluates the inner ear, specifically the saccule, utricle and the inferior and superior branches of the vestibulocochlear nerve. There are two types of VEMP tests: cervical vestibular evoked myogenic potential (cVEMP) and ocular vestibular evoked myogenic potential (oVEMP). cVEMPs measure the saccule and inferior vestibular nerve for the VCR reflex. The responses are inhibitory and measured on the sternocleidomastoid muscle. Electrodes are placed on the sternocleidomastoid muscle in the neck and on the forehead. A loud and abrupt auditory stimulus is presented through air or bone conduction to an ear and muscle activity is recorded. oVEMPs measure the utricle and superior branch of the vestibulocochlear nerve for the VOR reflex. The responses are excitatory and measured from the inferior oblique muscle. Electrodes are put under each eye and the forehead. Once again, a loud and abrupt auditory stimulus is presented through air or bone conduction to an ear and the muscle activity is recorded, however contralateral responses are often measured because they have the strongest response. Amplitude and latencies are compared between ears and analyzed regardless of the type of VEMP completed. Asymmetries greater than 33% are considered abnormal (Babu et al., 2019). Jacobson et al. (2020) reported that in oVEMPs, a 4kHz stimulus through air conduction will likely be absent in normal patients and a peak-to-peak amplitude above 17.1uV is indicative of a disorder such as superior semicircular canal dehiscence. Peak to peak values are impacted by age, so it is important to look at normative data. VEMP testing is sensitive to vestibular neuritis, Meniere's disease, Superior semicircular canal dehiscence, and more. This test can also be used alongside ENG/VNG testing to help diagnose vestibular disorders. oVEMP is more sensitive to disorders like superior semicircular canal dehiscence, while cVEMP is more sensitive in disorders such as Meniere's disease or vestibular neuritis.

A brief test known as the fistula test may be useful in identifying a disorder. This test applies pressure to the tympanic membrane through pneumatic otoscopy. Babu et al. (2019) reports that if a patient experiences vertigo or eye deviation it is abnormal and indicates a perilymph fistula, superior semicircular canal dehiscence, or labyrinthitis.

The rotary chair test measures eye movement with electrodes or infrared goggles while the chair moves. This test measures responses to head movement similar to daily activities and evaluates the VOR response at a wide range of frequencies, so it can identify disorders within the central or peripheral vestibular system. It is precise, reliable, and repeatable (Babu et al., 2019). The chair will move in a back-and-forth motion, or in a circular motion in a dark room. The speed is varied to test the entire range and capabilities of the vestibular system. There are three common rotary chair tests: sinusoidal harmonic acceleration, VOR reflex suppression, and velocity step test. Normal results indicate normal gain, phase points, and ability to suppress nystagmus. Abnormal results include low gain for low frequencies or all frequencies and low or high-frequency phase leads.

Lastly, video Head Impulse Test (vHIT) evaluates all six semicircular canals using a camera mounted in goggles in a lit room. The test evaluates eye movement during quick, unpredictable head movements controlled by the clinician. vHIT is a quick test that analyzes the VOR gain. VOR gain is the ratio of eye velocity to head movement velocity. Jacobson et al. (2020) reports normal VOR gain is around 1.0 and a latency of 10msec. An abnormal result, the patient will have a corrective saccade delayed after rotation of the head. The authors stress that before immediately jumping to normative data, analyze the data collected to ensure that the patient was not blinking or that the eyelid was drooping.

Each vestibular test has its advantages and limitations, so it is important to use a battery of tests along with a detailed case history to identify different disorders. Each test is summarized in Table 3. The tests mentioned above will be used in the next section which will specifically focus on the different disorders.

Vestibular Disorders

There are many different vestibular disorders with overlapping symptoms. Utilizing the knowledge of a vestibular test battery, the next section will focus on the different vestibular disorders and assessments necessary to differentially diagnose the disorders.

Table 3

Vestibular Tests and Expected Results

Vestibular Test	Brief Description	Normal Findings
ENG/VNG	Uses electrodes around the eye/ infrared goggles to analyze eye movement.	Ability to gaze at a target without nystagmus. Ability to track a moving target in smooth pursuit and saccade testing. Ability to induce nystagmus at a normal rate during optokinetic testing.
Calorics	Temperature controlled air or water is put in the ear and nystagmus is analyzed.	Cold stimulus, nystagmus beats to the opposite ear. Warm stimulus, nystagmus beats to same ear. Ability to fixate and suppress nystagmus during testing.
CDP	The patient will stand on a platform that shifts or visual targets that will shift to test the body's ability to maintain balance under different conditions.	Normal weight symmetry, active force strength and correction latency to maintain balance.
cVEMP	Measures the inferior vestibular nerve and saccule functions by playing a loud sound and analyzing the neck muscle responses.	Amplitude and latencies present based on normative age values and asymmetry is less than 33%.
oVEMP	Measures the superior vestibular nerve and utricle functions by playing a loud sound and analyzing the eye muscle responses.	Amplitude and latencies present based on normative age values and asymmetry is less than 33%.
Fistula Test	Applies pressure to tympanic membrane with pneumatic otoscopy.	No response
Rotation Tests	Evaluates how well the eyes and inner ear work together. The head is rotated at different speeds and the eye movement is recorded.	Normal gain, phase points, and ability to suppress nystagmus.
vHIT	Evaluates how the eyes and inner ear work together by using quick head movement.	VOR gain around 1.0 and a latency of 10msec

Benign Paroxysmal Positional Vertigo

Benign paroxysmal positional vertigo (BPPV) is one of the most common peripheral vestibular disorders (You et al., 2019). Symptoms of BPPV include sudden, brief episodes of intense spinning accompanied by nystagmus. This sensation is often initiated by certain head movements and the duration of the attacks are less than a minute. Other terms to describe BPPV may be imbalance with walking or standing. BPPV can develop in any of the semicircular canals. Two pathophysiologic models regarding the origin of BPPV are the cupulolithiasis model and canalithiasis model. The cupulolithiasis model involves the horizontal canal which opens to the cupula where the otoliths adhere to the cupula itself. Though this is rarer than the canalithiasis model, it can be diagnosed through the Pagnini-McClure maneuver, which is more commonly named the supine roll test. This test will stimulate both horizontal canals. The supine roll test should be used over the Dix-Hallpike maneuver because there will be no nystagmus if the Dix-Hallpike maneuver is utilized. The gold standard to diagnosing the type of BPPV is through observations of the nystagmus characteristics (Kim et al., 2021).

The canalithiasis model involves the semicircular canals. If there is a sudden movement there is a momentary lag before the otoliths move with the motion, but gravity pulls the otoliths downward causing the endolymph to flow away from the ampulla. This theory would also produce a nystagmus in the opposite direction (You et al., 2019). This theory can be modeled using a tire with pebbles inside. When the tire is rotated the pebbles will also rotate, but gravity will pull them to the bottom of the tire, instantly when the tire stops rotating. Specific diagnostic symptoms of canalithiasis BPPV in the posterior canal is having temporary vertigo while laying down in a supine position. The Dix-Hallpike maneuver isolates the posterior semicircular canals.

If the patient has posterior BPPV the nystagmus will have a latency of onset, in a geotropic directionality, and limited duration. The stronger the nystagmus the more severe the vertigo.

Most common etiologies of BPPV are idiopathic in origin. It is possible that degeneration of the vestibular system with age or ototoxic medications can cause BPPV as well as inner ear disorders like Meniere's disease or infection such as vestibular neuritis or labyrinthitis. Other causes of BBPV may be prolonged bed rest, displacement of the otoconia from otological or non-otological surgery, or head trauma like mTBI (You et al., 2019).

Primary treatment for BPPV is the Sémont or Epley maneuver which has over a 95% success rate (Strupp et al., 2020). The Sémont maneuver is used for patients with cupulolithiasis in the posterior or anterior canal. The Epley maneuver is also known as the canalith repositioning procedure which has a set of controlled movements to move the otoconia back in place utilizing gravity for the canalithiasis BPPV. A newer, modified form of the Epley/canalith repositioning procedure is called the particle repositioning maneuver which has only three movements and therefore more commonly used. The first movement is similar to Dix Hallpike maneuvers but instead of sudden movement, the head must hang off a surface in the intended direction for one to two minutes and then the patient is rolled 90 degrees to stimulate a secondary nystagmus (Kim et al., 2021). When the nystagmus is fatigued, the patient can sit up. To treat posterior canal BPPV the particle repositioning maneuver has a 70-85% success rate after just one treatment, but this treatment has also been successful for horizontal and anterior canalithiasis BPPV (You et al., 2019).

Another treatment option to reposition the otoliths in the horizontal canal with BPPV is the canalith maneuver or the barbeque/barrel roll. The head is turned toward the affected ear and the body is turned in the opposite direction. Each 90-degree turn is held for about a minute until a 360-degree rotation is completed and then the patient can sit back up. The last maneuver for horizontal canal BPPV is known as the Gufoni maneuver. In this maneuver the patient is quickly moved from sitting to laying on their side. After about a minute the head is rotated 45-60 degrees toward the ground for another couple of minutes before returning to a sitting position (You et al., 2019).

Other treatment options like surgery are rarely recommended. Finally, though controversial, some healthcare professionals will repeat Dix-Hallpike after treatment to ensure a negative test to prove that the treatment was successful, but a negative Dix-Hallpike could also be due to nystagmus fatigue. There is also a risk of undoing the successful treatment, so there is not a consensus on whether to perform the Dix-Hallpike maneuvers after treatment (You et al., 2019). There are many treatment options that have high success rates, but Jacobson et al. (2020) reports that BPPV may also spontaneously resolve.

Enlarged Vestibular Aqueduct

The vestibular aqueduct is housed within the temporal bone and is a tiny canal that extends from the endolymphatic space to the brain. The endolymphatic duct and sac are within the vestibular aqueduct, and the function is not well understood but likely due to electrolyte imbalance, specifically sodium, calcium, chloride, and potassium. An enlarged vestibular aqueduct (EVA) is considered abnormal when it is larger than 1.5mm and associated with conductive or sensorineural hearing loss that can be fluctuating or progressive as well as balance problems like episodic vertigo or imbalance difficulties (Zalewski et al., 2015). There have been a variety of studies analyzing vestibular symptoms and abnormal vestibular assessments; however, the data has a large range of variability. Stahl and Otteson (2022) report vestibular symptoms ranging from 2%- 71%. Of those who had further vestibular testing, 7%-91% had abnormal vestibular evaluation results. EVA can co-occur with BPPV, endolymphatic hydrops, or vestibular hypofunction (Song et al., 2018; Zalewski et al., 2015).

EVA is the most common inner ear malformation and many people do not realize they have this abnormality (Song et al., 2018). It is most likely congenital from birth and often asymptomatic, but symptoms such as sudden hearing loss and balance problems after head injury or barotrauma can induce symptoms. EVA is common with Pendred, Waardenburg's, Branchio-oto-renal syndrome, and other non-syndromic hearing losses (Zalewski et al., 2015). Formal diagnosis is through an audiological evaluation, vestibular evaluation using VNG and cVEMP and/or rotational vestibular testing, and a CT or MRI scan. Deep et al. (2016) reported that CT scans best identify the enlarged vestibular aqueduct, while an MRI will identify a large endolymphatic sac. CT scans are often quicker, more cost-effective, and have less radiation, but if there are any other concerns particularly looking at other structures, MRI may be the best option. It can be assumed that when one is abnormally large the other is as well. Historically, surgery was performed to remove or decompress the pressure and fluid in the endolymphatic sac, but the results have shown limited benefit (Gopen et al., 2011). Currently, there is no cure for EVA, but amplification is often used to treat hearing loss and multiple programs may be necessary for fluctuating hearing loss. EVA is not a contraindication for a cochlear implant as a treatment option for those with permanent severe to profound hearing loss. Song et al. (2018) recommended all patients with EVA and vestibular symptoms should undergo evaluation for BPPV and/or be treated with rehabilitation based on symptoms.

Labyrinthine Concussion

Labyrinthine concussion is a term for auditory/vestibular dysfunction following trauma to the head without temporal bone fractures. The pathophysiology of labyrinthine concussion is not well understood. A general theory is that the sudden acceleration/deceleration of movement causes the membranous labyrinth to hit against the bony labyrinth (Colucci, 2017). The trauma between the membranous labyrinth and bony labyrinth can cause hemorrhages within the inner ear, due to ruptured vessels, with or without a fracture. An intense blow to the head could cause a strong traveling wave transmitted through bone conduction and damage the inner hair cells (Bartholomew et al., 2020; Colucci, 2017). The last pathophysiologic theory is a cochleovestibular nerve traction injury resulting from the nerve fibers being pulled or sheared. Specifically related to the vestibular system, secondary endolymphatic hydrops can occur (Bartholomew et al., 2020). These theories have been studied for many years, but the precise pathophysiology of a labyrinthine concussion remains unclear.

Symptoms of labyrinthine concussion can include hearing loss, tinnitus, vertigo, and nystagmus following a head injury. Jacobson et al. (2020) reports true vertigo should be episodic and not spontaneous. Auditory symptoms can be separate or coincide with vestibular difficulties. Hearing loss is likely to be unilateral, and severity can range from mild to profound; more often a high-frequency sensorineural hearing loss or a flat sensorineural hearing loss. Colucci (2017) reported the following diagnostic signs to pay attention to: if a nystagmus is present, it will initially beat horizontally toward the impacted ear, however, during the recovery process, the nystagmus will beat in the opposite direction. Active head rotation is likely to have reduced gain, phase lag, and asymmetry. Dix-Hallpike testing may reveal an abnormal response. Caloric responses should be normal. Diagnostic results may have mixed signs for central and peripheral involvement. Postural control may be normal or impaired (Jacobson et al., 2020). Testing for labyrinthine concussion is mainly utilizing differential diagnosis to eliminate possibilities of other disorders. The object is to identify hearing loss and treat it accordingly as well as rule out other disorders, such as BPPV, perilymph fistula, and post-endolymphatic hydrops.

Perilymph Fistula

Perilymph fistula (PLF) is a tear or defect in the membrane leading to abnormal communication between the middle ear and the perilymphatic space in the inner ear. PLF can be a problem with the round window, oval window, an abnormal footplate, or fractured bony labyrinth. There are four ways that PLFs occur all through traumatic force. The first way can occur after head trauma, including direct labyrinth trauma, chronic inflammation, middle ear diseases, or otologic surgeries, etc. The second way is through external barotrauma events, like flying or diving. The third way is through internal barotrauma events such as sneezing, coughing, or straining. The last way is through idiopathic events (Deveze et al., 2018; Sarna et al., 2020). Symptoms of PLF include a sudden or progressive fluctuating unilateral hearing loss, rotational vertigo, disequilibrium, nausea, aural fullness, tinnitus, and cognitive dysfunction. A low-frequency sensorineural hearing loss may be present and mimic Meniere's disease, but it could also be a high-frequency hearing loss. Each patient will have a different set of symptoms; they may be purely auditory, purely vestibular, or a combination of both. Normally, changes in pressure that occur in the middle ear, do not affect the inner ear, but if a PLF is present middle ear pressure can affect the inner ear causing auditory or vestibular symptoms. Symptoms may get worse with changes in altitude, air pressure, or physical activity.

Due to the wide range of symptoms, it is important to collect an in-depth case history to try to identify a source of trauma that may indicate a PLF. There is no clear diagnostic tool, but an auditory and vestibular test battery is a good starting point. If PLF is suspected, high-resolution imaging can also be a valuable tool. For audiometric measurements, a full audiometric evaluation may be useful as well as positional audiometry. If there is a suspected side, the patient will lay down on that side for 30 minutes, then re-test pure tones. The test is positive if there is a threshold shift of at least 10dB in at least three frequencies (Deveze et al., 2018).

A battery of formal vestibular testing is also valuable. A VNG helps identify nystagmus. The fistula test puts pressure into the ear and monitors the nystagmus. If a nystagmus is present this is known as a positive fistula test or Hennebert's sign and indicative of a PLF. The Valsalva test is when the patient pinches their nostrils to create pressure. If there is a PLF a nystagmus should occur. Lastly, the Rhomberg test is when the patient stands heel to toe or ankles bones touching with eyes open and closed and the professional watches for swaying movement, which may be abnormal due to imbalance. cVEMP is beneficial in localizing the pathological side as well as caloric testing. Intra-operative visualization through a tympanotomy has been a gold standard to identifying PLF, but there is no consensus on what constitutes a perilymphatic leak. Cerebral spinal fluid and local anesthetics may also look like a perilymphatic leak during intra-operative visualization; therefore, this test is not as sensitive (Sarna et al., 2020). Recent research has led to a biomarker known as cochlin tomoprotein (CTP). CTP is present in higher doses in perilymph compared to CSF so if a patient is undergoing an intra-operative visualization procedure, a middle ear saline sample can be collected and analyzed for CTP (Deveze et al., 2018). Since this is a new procedure, it still lacks regulatory approval worldwide but has shown great success in Japan (Sarna et al., 2020).

To rule out other disorders, patients with PLF will be resistant to BPPV treatment and Meniere's treatment. Differential diagnosis will play a major role in diagnosing PLF. All the tests mentioned above can play a valuable role in diagnosing PLF, however, they are very time-consuming, therefore each test utilized should be determined by the audiologists and physicians for each case depending on the symptoms and potential causes. At minimum positional audiometry, cVEMP, and VNG, and Valsalva testing is advised (Deveze et al., 2018).

Treatment for PLF is either observation or surgery. In non-surgical cases, it is recommended to avoid situations that may cause pressure changes. Intratympanic steroids may also be used. Spontaneous healing of PLF has been recorded especially in those with limited impact on quality of life and idiopathic etiology. Patients who have progressive hearing loss or vestibular symptoms impacting the quality of life are recommended to have surgical intervention to seal the PLF as soon as possible. Post-surgery a range of 20-49% of patients experience an improvement in hearing and 80-95% experienced an improvement in vestibular symptoms (Sarna et al., 2020).

Superior Semicircular Canal Dehiscence

Superior semicircular canal dehiscence (SSCD) refers to an opening or thinning in the bone that covers the superior semicircular canal. It is also referred to as a third, round window. This opening can be congenital, from infection, or even head trauma, but most of the time the causes are unknown (McCrary et al., 2021). The prevalence of SSCD is unknown, but some studies report between 0.9-9% in the pediatric population (Mau et al., 2018). Prevalence is difficult to determine because some people may have SSCD without any symptoms and never know they have SSCD, while others will have debilitating symptoms affecting daily life. Some auditory symptoms of SSCD are autophony (hearing biological sounds like voice, heartbeat, footsteps, and breathing, louder than normal), hyperacusis especially with bone conduction testing, a false low-frequency conductive hearing loss due to an air bone gap with the absence of a middle ear pathology, pulsatile tinnitus, and aural fullness. Vestibular symptoms include vertigo, oscillopsia (appearance of movement in stationary objects), rotary nystagmus, chronic disequilibrium, and a rotary nystagmus from the Tullio phenomenon and Hennebert's sign due to endolymph displacement. Diagnosis is challenging due to the wide range of symptoms that may overlap with other disorders like perilymph fistulas, but the rotary nystagmus is specific to SSCD. Another test that is specific to SSCD is a tuning fork test that places the fork on the medial malleolus of the ankle. The patient should not feel the tuning fork on the ankle but will hear it due to bone conduction hyperacusis (Mau et al., 2018). To diagnose this disorder, taking symptoms into account, a full hearing evaluation is recommended and VEMP testing. The full auditory evaluation will help elucidate the auditory symptoms like the conductive low-frequency hearing loss with present acoustic reflex thresholds, while VEMP testing will differentiate between the middle ear and inner ear pathologies and measure the auditory nerve response. A patient with SSCD should have lower than normal thresholds for eliciting oVEMP responses and larger amplitude. While cVEMPs can also be used, the responses are greater in oVEMPs making it easier to interpret and oVEMPS have above 90% specificity and sensitivity to identifying SCCD. Between symptoms, full evaluation, and VEMP testing it should elucidate the diagnosis, but a CT temporal bone imaging scan will also confirm the diagnosis (Mau et al., 2018).

Tikka et al. (2021) looked at the use of vHIT, which would not help diagnose SSCD, but it could be a useful tool to demonstrate the impacts of surgery on patients to help avoid bilateral vestibular failure. vHIT could help analyze the responses from the contralateral ear which could be bilateral SSCD, a pre-existing contralateral vestibular disorder, or normal. vHIT looks at the whole system rather than just one ear.

A survey completed by the American Neurotological and Otologic Societies reported that 81.5% of surgeons recommended symptomatic treatment, like amplification, medications, and vestibular rehabilitation before surgical intervention (Walsh, 2020). About 50% of patients with

SSCD will have debilitating symptoms, in which there are four surgical options to plug or resurface the dehiscence, each with advantages and disadvantages. The first is the middle cranial fossa approach which does a craniotomy to get direct visualization of the dehiscence, but it is very invasive. The second option is an endoscopic approach which also does a craniotomy but in a smaller segment that still requires temporal lobe retraction but is less invasive than the middle cranial fossa approach and offers direct visualization. The third option is a transmastoid approach, which is growing in popularity. The transmastoid approach involves a mastoidectomy which is less invasive than the other two approaches, but there is no direct visualization of the dehiscence. Lastly, the transcanal/endaural approach closes the round window instead of the dehiscence and potentially has decreased longevity of the treatment. Walsh (2020) reported no statistical differences between treatment approaches and techniques. Many were successful in treating SSCD and therefore are recommended to those with debilitating symptoms.

Endolymphatic Hydrops

In a normal ear, endolymph is fluid in the cochlea and the semicircular canals with a proportion of sodium, potassium, chloride, and other chemicals. Endolymph plays a role in sound and vestibular transmission, but when the volume or concentration within the endolymph changes it can cause episodes of vestibular and auditory symptoms. There are two forms of endolymphatic hydrops: primary and secondary. Primary endolymphatic hydrops is when the cause is unknown. This is also called Meniere's disease (MD) which is an inner ear disorder that is characterized by four symptoms including aural fullness, tinnitus, fluctuating hearing loss and episodic vertigo. Patients may experience a cluster of attacks and then a long period without any symptoms. Professional organizations from the Classification Committee of Bárány Society and the American Academy of Otolaryngology-Head and Neck Surgery have two diagnostic categories: definite and probable MD. Definite MD is defined as two or more episodes of vertigo lasting 20 minutes to 12 hours, fluctuating aural symptoms, and identifiable low frequency sensorineural hearing loss. Probable MD is two or more episodes of vertigo lasting 20 minutes to 12 hours with aural symptoms, but no hearing evaluation available (Babu et al., 2019; Patel & Isildak, 2016). Even if patients fall into one of these categories, differential diagnosis is still necessary. Electrocochleography and electronystagmography are two tests that can be performed to diagnose MD. When there is elevated endolymphatic pressure the summating/action potential ratio is enlarged, because the action potential area is increased; however, this can also be observed in SSCD. cVEMP and oVEMP responses are often decreased in patients with MD, but the sensitivity is also not high.

Secondary endolymphatic hydrops (SEH) or post-traumatic endolymphatic hydrops can occur after any form of trauma, including head injury, ear surgery like cochlear implantation, stapedectomy, allergies, history of infection like mumps, measles, or meningitis, and lastly, medications such as Vasopressin (Ferster et al., 2017). Symptoms are the same as MD with tinnitus, aural fullness, hearing loss, episodic vertigo, and disequilibrium; however, compared to primary idiopathic hydrops seen in MD, SEH have continuous symptoms that are less aggressive and likely causes less long-term damage.

To diagnose SEH, collecting a detailed case history is a priority. Other tests such as electrocochleography and imaging like MRIs can help diagnose endolymphatic hydrops but will not be able the differentiate the difference between primary and SEH, which is why case history is important to see if there is an underlying cause that can be matched with the onset of symptoms. Differential diagnosis may also be necessary to help eliminate other potential causes for symptoms like vertigo or fluctuating hearing loss. That may include hearing tests, VNG, electrocochleography, or VEMP testing. Don et al. (2005) looked at auditory brainstem response (ABR) with high pass masking and found 100% sensitivity in distinguishing those having active endolymphatic hydrops episodes and those without.

Currently, there is no cure for MD or SEH, but there are lifestyle modifications, medications, and other forms of therapy that may relieve some symptoms (Pesznecker, 2017). The goal is to stabilize body fluids and chemicals which sometimes can be accomplished through diet modification which includes eating meals at the same time each day, limiting salt intake, caffeine, alcohol, and tobacco products. Other lifestyle modifications include daily exercise, losing weight, reducing stress, and good sleep habits. For medications, there is limited literature, but some studies recommend loop diuretics to be taken to help balance electrolytes in the endolymph. Other medications that may help treat the symptoms include vestibular suppressants like antihistamines and benzodiazepines for vertigo and aural fullness and antiemetics for nausea. Medications like aspirin or ibuprofen should be avoided because they can throw off chemical balance and may make some symptoms like tinnitus worse. For those who do not benefit from lifestyle modifications and medications, more extreme treatment may be recommended such as micropressure therapy, intratympanic injections, and surgical therapy, but there is limited evidence supporting these treatments. Micropressure therapy will apply pressure to the tympanic membrane and some patients have experienced a decrease in frequency and severity of attacks (Patel & Isildak, 2016). Intratympanic injections are steroids given to the tympanic membrane which directly affects the perilymph. Unfortunately, some steroids like gentamicin are ototoxic and can cause more permanent hearing loss, so it should be used with extreme caution. Lastly, surgery is often the last option for patients with no success with non-invasive procedures and have persistent, debilitating symptoms after three to six months.

Endolymphatic sac surgery alters the endolymph volume and pressure. There are mixed results, but some studies suggest improved hearing and fewer and less severe attacks (Patel & Isildak, 2016). Tympanostomy tube placement may help alleviate pressure and a triple semicircular canal plugging, cuts off endolymphatic flow between canals, often in the horizontal canal and may relieve vestibular symptoms (García et al., 2017), while more destructive procedures like labyrinthectomy and vestibular neurectomy eliminate the source causing vestibular and auditory problems but can cause permanent hearing loss (Patel & Isildak, 2016; Zhang et al., 2021).

Persistent Postural-Perceptual Dizziness

Persistent postural-perceptual dizziness (PPPD) is a disorder in the central or peripheral vestibular system where symptoms of imbalance, dizziness without vertigo are present for at least three months. Jacobson et al. (2020) and Staab (2020) describe three possible diagnostic criteria based on the classifications of vestibular disorders of the Bárány Society. The first criteria group includes dizziness or unsteadiness for three months or more with persistent symptoms at least 15 out of 30 days a month. The symptoms must be continuous periods throughout the day and the symptoms may worsen throughout the day. Lastly, flare-ups may occur with sudden movements. The second criteria: the symptoms are worsened by upright posture, exposure to complex visual stimuli, and active or passive motion despite direction. In the last criteria group, the disorder may begin after an event or after a peripheral or central vestibular disorder. Common comorbidities or disorders include BPPV, MD, and mTBI. Patients with anxiety and depression also tend to have higher rates of PPPD.

PPPD is an all-encompassing term to describe a disorder without an identifiable etiology. Staab (2020) classified three cases of PPPD based on etiology: otogenic, psychogenic, and interactive pattern where the primary etiology may be due to a vestibular disorder but exacerbated by anxiety. Typically, there are no other auditory signs, and all vestibular tests are normal, unless there is an already diagnosed comorbidity. Jacobson et al. (2020) report that some patients with PPPD will have a pattern on the SOT portion of the CDP test, demonstrating abnormal performance on the easier conditions, but significantly improved performance on the more difficult conditions.

Classic treatments for PPPD include medications, treatment for comorbidities, general vestibular balance rehabilitation therapy, and/or counseling. Drug treatment for PPPD are often serotonin reuptake inhibitors and Bittar and Lins (2015) reports that about 70% of patients will experience symptom relief in approximately three months. Thompson et al. (2015) completed a prospective study that concluded that physical therapy was beneficial in 22 out of 26 patients with PPPD. More recent literature also reported similar statistics, though there is a need for larger, more recent studies. Whether medications or rehabilitation therapy is the chosen treatment option, there is a high success rate in the reduction of symptoms.

Vestibular Migraine

Migraines are intense headaches that may cause throbbing in a localized area, may induce nausea, photophobia, and hyperacusis. Vestibular migraines (VM) are similar; however, they are accompanied by symptoms like vertigo and disequilibrium. Some auditory symptoms include tinnitus and aural fullness. Unlike regular migraines where symptoms last with the headache, vestibular symptoms may precede the headache or last one minute to 72 hours later. Brainstem auras also have overlapping symptoms, but the patient must have at least two symptoms present after a headache. Most patients with VM do not meet the aura time window (Beh, 2019). These symptoms are common to other vestibular disorders; therefore, it is difficult to diagnose. VM are 1.5-5 times more likely to occur in women than men (Brandt & Dieterich, 2017). VM is considered a central vestibular disorder, but it may also coexist with peripheral vestibular disorders as well, such as BPPV or Meniere's disease (T. C. Huang et al., 2020). Brandt and Dieterich (2017) reported a retrospective study that found 13% of the patients fulfilled diagnostic criteria for both VM and Meniere's disease. Despite coexisting disorders or common overlap in symptoms, vestibular migraines are the second most common cause of vertigo following BPPV and the most common causes of spontaneous episodic vertigo (Lapira, 2019).

The pathophysiology in VM is unknown. The vascular theory was based on the idea that the blood flow may be constricted, such as an ischemia followed by vasodilation stretching the walls of arteries. Both constriction and vasodilation are viable options to cause pulsatile headaches, however recent literature supports neurochemical imbalance theories including cerebral spreading of depression. Hypersensitivity to light and sound is likely due to the electrical signals firing. Though there is no distinct etiology, a combination of the vascular and neuromodulation theories are likely the cause of the VM.

Currently, there are no specific diagnostic criteria. Diagnosis is solely based off of clinical symptoms and history. It is not uncommon for neurological and vestibular assessment, but literature reveals conflicting conclusions for identifying VM in ABRs, calorics, VHIT, cVEMP, and oVEMP testing (T.C. Huang et al., 2020). Some patients may present with abnormal vestibulo-ocular results, but some will not, which is why this is not commonly used in diagnosis, but rather differential diagnosis. VEMP testing is useful in differentiating between MD and VM. ABR has no specific abnormalities to VM but may help rule out lesions in the auditory or central pathway through the brainstem and peripheral auditory system. Nystagmus and vertigo cured by canalith repositioning maneuvers indicate BPPV, but if the symptoms are present after treatment, VM should be suspected (Beh, 2019). Electrocochleography may be useful in differentiating between MD and VM. MRI is recommended if patient has unilateral cochleovestibular symptoms to eliminate tumors (Lapira, 2019).

There is no specific treatment to cure VM. Patients can take preventative measures such as moderate exercise, reducing stress, good sleep habits, and avoiding triggering foods. Common trigger foods are aged cheese, red wine, caffeine, chocolate, and processed meats. Vestibular physical therapy is a common form of management, specifically doing activities that enhance visuospatial awareness like playing music or a sport. Medications such as antihypertensives and antidepressants have been used to prevent migraines in general, but the evidence supporting this is insufficient (T.C. Huang et al., 2020). Lastly, medications to treat side effects such as antiemetics for treating nausea or Rizatriptan for motion sickness, and triptan for longer term headaches have been used, but efficacy is also limited (Beh, 2019; T.C. Huang et al., 2020). Lapira (2019) reported that betahistines used for MD and topiramate used for seizures and migraines and flunarizine have shown promise in controlled studies. With more research in the future there may be a drug available for treatment against VM. Lastly, psychiatric help may be useful in cases of comorbidity, especially if a patient has anxiety or depression from migraines.

Conclusion

There are other vestibular disorders, such as labyrinthitis, vestibular neuritis, cervical vertigo, Mal de Barquement Syndrome, neurotoxicity, vestibular paroxysmia, vertebral insufficiency and many more that may have overlapping symptoms but have other defining characteristics and have not been reported commonly correlating with mTBI. Recently, more research has been conducted to understand different vestibular disorders, how to diagnose, and treat. Unfortunately, there are very few disorders with gold standards, making it difficult to formally diagnose and find etiology. Audiologists often play an important role in diagnosing vestibular disorders, but rarely in mTBIs. This leads to the question: what is the audiologist's role as a part of a multidisciplinary team to help differentially diagnose, monitor, and manage vestibular symptoms secondary to mTBIs?

CHAPTER II

AUDIOLOGIST'S ROLE IN MANAGING MILD TRAUMATIC BRAIN INJURY PATIENTS

Audiology Scope of Practice

The American Academy of Audiology (AAA) is one of the largest professional organizations for audiologists in the United States. The first scope of practice document was completed in 1992; with revisions in 1996, and 2004 (American Academy of Audiology, 2004). This document lays out the interests, capabilities, and job duties for audiologists based on the education received through academics and clinical training. Due to an expanding scope of practice necessitating extensive graduate training and education, in 2007, the entry-level degree to practice audiology transitioned from a master's degree to a clinical doctoral degree (Allen et al., 2008). Graduate education in audiology includes a variety of content including anatomy and physiology of the peripheral and central auditory system, otologic disorders, pharmacology, case history and interview techniques, training on test protocols, interpretation of results, and rehabilitation. Coursework is both didactic and clinical in nature. An audiologist is a licensed professional uniquely qualified to provide comprehensive services relating to the prevention, identification, assessment, and treatment relating to the auditory and vestibular systems. Audiologists' professional roles may be in the form of a clinician, therapist, professor, researcher, consultant, and/or supervisor. Audiologists may complete hearing screenings for industrial or educational settings, work in medical or private practice settings to test and interpret behavioral and electrophysiologic measurements in the peripheral and central auditory system, remove cerumen, and rehabilitate hearing loss with amplification, assistive listening devices, aural rehabilitation, and vestibular rehabilitation.

Similar to other professions, audiologists may choose to specialize in an area of practice based on personal choice, education, and experience. Some areas that audiologists choose to specialize in include, but are not limited to, pediatrics, cochlear implants, educational audiology, interoperative monitoring, and vestibular assessment and management. As education and training varies, the American Academy of Audiology advises that audiologists should not assess or treat patients if they are not up to date on knowledge and clinical skills. This is particularly important for vestibular disorders, as many patients who refer in this area have a complex medical history. For example, audiologists who work solely with hearing aids are likely not the best option to refer out to for a vestibular assessment. The American Academy of Audiology Code of Ethics (2019) Principle 2a states that audiologists must demonstrate professional competence by providing quality service based on education and training. Audiologists must also utilize resources and make appropriate referrals, take reasonable precautions to avoid injury to patients, comply with the code of ethics and participate in continuing education. By being an audiologist and member of the American Academy of Audiology, these principles hold audiologists accountable for the services they provide to patients. Principle 2 focuses on ensuring that while audiologists may have been trained in specialty areas such as vestibular audiology, if the training is not up to date, it is not advised to treat patients in that area to keep them safe and provide the best services. If that is the case, the audiologist should refer to another audiologist that specializes in this area or another professional better equipped to help the patient. The American Speech-Language Hearing Association, Academy of Doctors of Audiology, and other professional organizations have similar scope of practice guidelines, and each state has a similar scope of practice document but may have some different laws and regulations.

While audiologists still have similar roles as in the 2004 AAA scope of practice, the profession is evolving. Audiologists may play a valuable role in preventing, assessing, and treating different disorders. A new area in audiology that is emerging is in the assessment and treatment of traumatic brain injuries (TBI). It is possible that a revised scope of practice may be necessary in the near future to specifically include TBIs as a disorder under the vestibular umbrella. Currently, it is uncommon for patients with mild traumatic brain injuries (mTBI) to be referred out to an audiologist, however many patients with mTBI complain of dizziness, which can be evaluated through vestibular assessments that specialized audiologists complete. Many other medical professionals forget or overlook the value of audiologists in this area. In the next section, an overview of common vestibular dysfunction that co-occurs or is secondary to mTBIs are reviewed to expand upon the potential need for audiologists to be a part of a multidisciplinary team.

Vestibular Disorders Secondary to Mild Traumatic Brain Injuries

As mentioned in the literature review, there are many vestibular disorders, some that happen secondary to mTBI. There is growing evidence that mTBIs may affect more than just the cerebrum. This can be demonstrated based on one of the most common complaints: dizziness. Dizziness is a frequently used catch-all term because patients do not know how to describe what they are feeling and how to distinguish it from lightheadedness, disequilibrium, imbalance, or vertigo. Dizziness can be central or peripheral in origin therefore there is an overlap in mTBI that affects the central system and mTBI with dizziness stemming from the vestibular system. The inability to rehabilitate for traumatic vestibular loss may result in prolonged dizziness in individuals with mTBI, therefore it is crucial to provide the right assessment and management for these patients and their related vestibular symptoms.

Misale et al. (2021) analyzed a large database with 4,291 workers with head injuries and reported dizziness. The purpose of this study was to look at the most common vestibular disorders following mTBI. A total of 26.9% of workers in this study had dizziness relating to a vestibular disorder. Benign positional paroxysmal vertigo (BPPV) is the most common vestibular disorder in this study with 908/4291 workers diagnosed and it was most common in the posterior canal. Non-positional peripheral disorders were reported in 5.6% of workers with mTBI (244/4291 workers). More specifically, 78/244 were diagnosed with recurrent vestibulopathy, 11/244 with probable Meniere's disease (MD), 10/244 with secondary endolymphatic hydrops (SEH), 9/301 with drop attacks, 3/244 with superior semicircular canal dehiscence (SSCD), 77/244 with fixed vestibular loss, 56/244 with undiagnosed peripheral dysfunction, and 56/244 with "other" positional vertigo (Misale et al., 2021). Based on this study, over 25% of patients with complaints of dizziness after mTBI may have a vestibular disorder secondary to mTBI and deserve proper assessment and treatment.

A smaller study was completed by Brodsky et al. (2018) on the prevalence of peripheral disorders in pediatric populations with a head injury. One hundred and nine patients were evaluated following mTBI. Twenty eight out of the 109 (25.7%) patients were diagnosed with peripheral disorders which is a similar statistic to Misale et al. (2021). Nineteen out of 28 patients had BPPV and underwent canalith repositioning successfully, 3/28 with temporal bone fractures, 2/28 with perilymph fistulas (PLF), and 2/28 with SSCD and three undiagnosed disorders. This article demonstrates that peripheral disorders post mTBI also occur amongst pediatric populations that appear to align similarly to other studies relating to prevalence.

Mucha et al. (2018) compared adult and children prevalence rates of BPPV post mTBI and reported that 15% of adult patients with mTBI also had BPPV, but only 5% of children with mTBI had BPPV. Children are less likely to experience BPPV following concussion, compared to adults who acquire mTBIs from accidents, falls, and military trauma. This demonstrates that adults may be more at risk for different vestibular disorders than children.

SSCD that occurs after an mTBI is referred to as posttraumatic SSCD. McCrary et al. (2021) completed a retrospective study to analyze 14 patients with posttraumatic SSCD, 43% bilateral and 57% unilateral SSCD. They had a variety of symptoms from pulsatile tinnitus, autophony, hearing loss, vertigo, and more. Eight patients underwent surgery and reported at least partial improvement in symptoms, but the amount of improvement varied among patients. Though there is limited literature, discussing the comorbid findings, McCrary et al. (2021) proposed a theory known as the “two-hit theory” where they suggested that patients with SSCD symptoms after head trauma may have had underlying SSCD and the head trauma exacerbated the symptoms. SSCD prevalence increases with age, therefore the first hit is likely due to the gradual thinning of bone that also occurs with aging. A second hit occurs when head trauma or increase of barometric pressure takes place and leads to SSCD symptoms. This theory was supported by Misale et al., (2021) who reviewed several studies and found that about 27% of TBIs with SSCD were most likely caused by a predisposed thinning of bone that opens with trauma.

Similar to SSCD, other vestibular disorders like enlarged vestibular aqueduct (EVA), or MD occur due to genetic pre-disposition but may be brought to attention after a head injury. Specifically, EVA is commonly reported to be found when there is a sudden hearing loss and vertigo after mTBI, however, the vestibular aqueduct was likely already enlarged at birth, but asymptomatic until trauma. Fife and Giza (2013) reported less than 3% of people with MD are due to head trauma, also referred to as post-traumatic MD or non-infectious MD.

Hundreds of cases of PLF after trauma have been reported (Fife & Giza, 2013; Fitzgerald, 1996; Kushner, 1998). PLF often occurs after temporal bone fractures that occur with mTBI but may also be due to pressure. A small retrospective analysis completed by Marzo et al. (2004) assessed and treated 16 patients with head trauma and residual vertigo. Five out of 16 patients had symptoms consistent with PLF, including tinnitus, aural pressure, sensorineural hearing loss, and vertigo after a mTBI, however, none of these patients had obvious fistulas during exploratory surgery for repair. Two out of five of these patients were able to return to work and daily activities, while the others report debilitating disabilities preventing return to work with no other diagnosis found. Despite many cases of PLF or symptoms that are consistent with PLF reported, evidence from Marzo et al. (2004) supports why the prevalence and detailed pathophysiology of the disorder is sparse.

Migraines are a neurological disease that causes symptoms such as intense, pulsating headaches, photophobia, phonophobia, nausea, and fatigue, with or without an aura. Migraines are a cause of persistent headaches from mTBIs. Vestibular migraines (VM) are a variant of migraines with vestibular symptoms such as vertigo and disequilibrium. VMs are more commonly diagnosed following mTBIs than the general population without a history of head trauma. Mucha et al. (2018) found multiple studies reported that 40% or more patients with mTBI were also diagnosed with migraines and migraine-associated dizziness, now referred to as vestibular migraines.

Collins et al. (2014) proposed clinical profile models to categorize the most common difficulties after mTBI. The clinical profiles were cognitive fatigue, vestibular difficulties, ocular difficulties, posttraumatic migraine, mood difficulties, and cervical difficulties. Using the clinical profiles from Collins et al. (2014), another study was completed by Kontos et al. (2019), where the researchers evaluated 226 participants post mTBI and found that the most common profile post mTBI was migraines (26%), followed by mood disorders (24%). The vestibular (19%) and ocular (16%) profiles together made up over a third of patients. The last profile was cognitive fatigue which accounted for 11% and the remaining 4% fell in the cervical profile.

There are also secondary profiles that go hand in hand with primary profiles. The most common pairings found were primary vestibular dysfunction secondary with ocular and migraines. The implications of this pairing demonstrate that vestibular and ocular assessments should be done together because results from one may affect the other. By categorizing patients into profiles, it may help guide more efficient assessment and treatment plans for patients. Those with vestibular profiles should be assessed more thoroughly by a multidisciplinary team familiar with mTBIs and utilizing many different tests to diagnose and treat all the symptoms.

Lastly, other disorders like labyrinthine concussion, and PPPD are recorded in literature because of head injury, though there is minimal literature related to prevalence in relation to mTBI in this area. There are also many reports of patients that have undiagnosed peripheral vestibular disorders which become evident based on abnormal test results during vestibular assessment (Misale et al., 2021; Mucha et al., 2018). Some abnormal results for videonystagmography (VNG)/electronystagmography (ENG) may include spontaneous or rotational nystagmus, overshooting or undershooting during gaze testing, irregular tracking during smooth pursuit testing, abnormally slow phase velocity during optokinetic testing, and/or inability to suppress nystagmus with fixation during calorics. During vHIT testing, corrective saccades are delayed after rotation. During rotary testing, abnormal results include low gain for any frequencies and/or high-frequency phase leads. Lastly, for CDP, abnormal results will include slow latencies when making corrections to balance.

Sassano and Pouncey (2020) described a case study of a patient in their mid-30s who was involved in a snowboarding accident resulting in a head injury. The patient reported symptoms of lightheadedness, room-spinning vertigo every couple of days, floaters in vision, and imbalance. The patient had a history of migraines, which were more common after the head injury, but no other notable symptoms. A comprehensive balance assessment was completed including VNG, vHIT, and CDP testing. VNG and vHIT findings were all within normal limits, while CDP was primarily normal except for a few atypical findings in the least dynamic SOT conditions. Fife and Giza (2013) also found abnormal SOT results in sports-related mTBIs. In the past, CDP was a tool used to identify the impact of balance after head injury. CDP may not be sensitive enough to detect the impact of balance a after head injury, therefore patients with athletic backgrounds may still have normal balance results after head injury due to the use of heightened proprioception within sports (Fife & Giza, 2013; Sassano & Pouncey, 2020). Without baseline testing completed prior to head injuries after sports, it is hard to evaluate and justify noticeable balance differences reported by athletes. Providers must be aware that athletic ability may influence test results. Athletes with vestibular dysfunction may still be good candidates for vestibular rehabilitation, despite normal vestibular results.

It is clear from the evidence presented that there is an overlap in mTBIs and at minimum, vestibular symptoms and abnormal vestibular assessment results, however only a small percentage of patients will have a specific vestibular pathology. Though only a small percentage of patients with mTBI have vestibular pathologies, that small percentage significantly impacts patients who do not get proper treatment. An excellent example of this was experienced by an acquaintance of the author and detailed in a case study that follows.

Mild Traumatic Brain Injury with Benign Paroxysmal Positional Vertigo- A Case Study

T.S. was a 19-year-old female who complained of physical pain, headache, vomiting, trouble concentrating, light sensitivity, fatigue, and dizziness after hitting her head against a wall while springboard diving. T.S. was sent to the athletic trainer about 20 minutes after impact on September 14, 2019. The athletic trainer completed a concussion screening test, including memory and balance subtests, though the patient did not know the names of the specific tests she was given. T.S. recalls being asked to stand on one leg with her eyes closed, walk backwards, and repeat a list of words back. T.S. did not have a baseline test, but the athletic trainer reported that she “passed” the balance screening but “failed” the cognitive subtest. T.S. reported that as a diver whose sport is focused on spatial awareness and balance, her balance was significantly worse than before, emphasizing the necessity for baseline testing. Based on symptoms and the cognitive screening, she was diagnosed with a mild concussion and told to go home and rest. After symptoms persisted overnight, T.S. revisited the athletic trainer who created a treatment plan which consisted of no classes, limiting time in bright lights, mainly avoiding being outside without sunglasses and staying away from the pool. T.S. also had to limit time on technology, including phone, computers, and no television. As symptoms improved, she slowly added school and daily activities back into her routine.

Most symptoms improved by one month, but as T.S. began return-to-play protocol to get back into her sport, she continued to complain of persistent dizziness when she did certain drills. The dizziness was episodic and especially bad when she would make sudden movements. T.S. described it as “the world spinning” and feeling like she “just got off a boat” causing her to be off-balanced and disoriented. T.S. explained that the dizziness was different than just feeling unbalanced when she had first gotten the concussion, though she was not doing sudden movements during her concussion recovery. On one of her first practices back, she did a dive and after she got out, she reported that she was still spinning. T.S. tried to complete another dive, but because the ground and springboard appeared to be moving when it was still, her knees buckled, and she smacked on the water. After this event, T.S. was pulled out of practice. The athletic trainer suspected that her concussion was not healed, but due to extreme dizziness and vomiting she sent T.S. to the student health center where she was seen by a nurse who suspected BPPV. The nurse did no tests to confirm the BPPV diagnosis. After T.S. personally reported this back to the athletic trainer, she was seen four days later by the sports medicine doctor who completed the Dix-Hallpike maneuver and formally diagnosed her with BPPV.

T.S. completed rehabilitation with the athletic trainer doing exercises like canalith repositioning. The athletic trainer was not well versed in this area, so T.S. was expected to do the repositioning on her own after a brief training session with the physician. After about one week the rehabilitation started to help decrease the severity of vertigo, and after 20 days T.S. reported that the vertigo was completely gone during daily activities and during her sport. T.S. completed a return to play protocol which took one month, and she was released back to her sport with zero restrictions from concussion and BPPV five months later. As a springboard diver who is highly reliant on their vestibular system for proprioception, vertigo impacted her safety while competing and limits daily activities. T.S. still reports random vertigo spells up to two years after the mTBI, often brought on my situations with increased barometric pressure, such as traveling in a plane, in the car for long periods of time, especially through mountains.

T.S. expressed her frustration throughout the mTBI injury and recovery process during the interview. When she was finally diagnosed with BPPV the physician walked her through repositioning techniques, but never completed them on her and she was left to struggle through the rehabilitation herself as her athletic trainer had no expertise in this area. There was also minimal formal communication between the athletic trainer, sports physician, and nurse. T.S. was the middleman relaying information. Some things T.S. wished went differently, included a referral to a physician or audiologist trained in the area of vestibular disorders for diagnosis and treatment.

Based on this interview it is evident that audiologists may provide valuable information to help diagnose dizziness in patients with mTBI. This would result in working with a multidisciplinary team to best serve this patient population.

Benefits of a Multidisciplinary Approach

Multidisciplinary teams are when a group of professionals work together to efficiently solve or treat a problem. It is often used in the medical environment to help treat patients who have many different symptoms and complex medical histories. While physicians are well-versed in knowledge pertaining to general medical health, it is unavoidable to have a weakness in certain areas, therefore working with another professional that either specializes or is better versed in an area may be beneficial. Pedrick (2022) recommends a physical medicine and rehabilitation (PM&R) doctor. PM&R doctors complete medical school followed by a residency that specializes in non-surgical diagnosis and management of musculoskeletal and neurological injury, which includes brain injury medicine. In hospitals with brain injury units, these are the types of doctors who specifically manage TBI patients. Neurologists and neurosurgeons specialize solely in brain injury medicine like PM&R doctors, therefore are good resources, but tend to focus more on the diagnosis and other neurological disorders, so the patient will likely be transferred to care by their PCP or the preferred choice, PM&R doctors.

Rodriguez et al. (2017) completed a retrospective study to compare dizziness diagnosis trends with and without an interprofessional management approach. The study was completed over three years with years one and two without interprofessional management and year three implementing a team approach. Within this study, the interprofessional team consisted of a primary care physician (PCP), Ear Nose and Throat Doctor (ENT), neurologist, audiologist, physical therapist, and pharmacist. In this specific study, all patients referred to ENT for dizziness would be triaged to audiology before any other specialty and a full vestibular evaluation was completed. After the evaluation, the lead audiologist reported back to the interdisciplinary team. Together, the team verified a diagnosis, if any, and future treatment recommendations were made. If no diagnosis was reached, the patient is sent to the next most likely specialist.

Based on the results from Rodriguez et al. (2017), ENTs referred 84% of patients to audiologists for vestibular testing followed by PCPs only referring 42% of patients with dizziness complaints. This is likely due to the ENT's awareness of the value of vestibular testing and the overall rate of misdiagnosis from the primary care level. PCPs often referred to ENTs over audiologists. ENTs will likely send the patient to an audiologist for vestibular testing, so it is possible to reduce a step for the patient by referring them straight to an audiologist who will report to an ENT or another medical specialty doctor. The most common disorders diagnosed in years one and two were vestibular hypofunction and BPPV, however, in year three when the interdisciplinary team was put in place, there was a wider range of disorders identified including central disorders such as VMs. Due to increased and more accurate diagnoses, there were more specific diagnosis (ICD-10) codes and procedural (CPT) codes billed to insurance rather than just the general dizziness ICD and CPT code. Patients included in this study reported better subjective improvement of symptoms during year three. Overall, interprofessional management in this study was reported to be valuable as it reduced the number of secondary referrals, which decreased unnecessary physician visits, patient wait time, lowered financial costs, patient satisfaction, and better ability to diagnose disorders.

A multidisciplinary-based approach allows for more accurate diagnoses and assessment catered to the patient's symptoms which also saves time, money and leads to the best treatment recommendations. Many professions associate audiologists solely with auditory complaints, though audiologists specialize in vestibular and auditory knowledge more than many other professions and can provide the most thorough assessment of vestibular problems with equipment like VEMP testing, rotary chair testing, ENG/VNG testing, and more. Other professions like medical doctors, physical therapists, and athletic trainers may diagnose and treat vestibular symptoms along with mTBI management, however, due to the expertise in the vestibular field and auditory field, an audiologist may also be a valuable resource. After much research, mTBI assessment, management, and treatment guidelines fail to acknowledge auditory and vestibular symptoms as unique entities that would benefit from a specialized assessment and treatment plan, thus leaving audiologists out of the situation. Specialized assessment, management, and treatment plans can help the patient recover from both the mTBI and post-concussive symptoms more efficiently and thoroughly.

Military service head injury guidelines are a unique exception in that the military already has audiological and vestibular assessments in place due to common head injuries that co-occur with noise-induced hearing loss and blast-related injuries. The Department of Veteran Affairs and Department of Defense have clinical guidelines based on an algorithm process to assess mTBI symptoms including auditory and vestibular related symptoms. It is crucial for military members to get full assessments completed due to many symptoms in different fields such as physical injury and/or psychological distress. Sometimes post-traumatic stress disorders (PTSD) and mTBIs have overlapping symptoms such as sleep disturbances and emotional disturbances. To differentiate between mTBI and PTSD, often mTBI testing is completed first, followed by audiological and vestibular testing and management, then psychological assessment. While assessment is completed in these areas, it is often not prioritized until urgent life-threatening issues are already addressed. The Department of Veteran Affairs and Department of Defense sets a guideline standard of care much higher than assessment and management on the sports field or medical evaluations from falls or motor vehicle accidents. The lack of auditory and vestibular assessment in the athletic world or medical evaluations from motor vehicle accidents can easily be addressed with a clinical interview that asks questions about the vestibular and auditory symptoms to help determine whether a referral to audiologists may be valuable or even necessary.

The World Health Organization (2019) recently reported the global impact of mTBIs and the barriers that prevent treatment. Lack of treatment can lead to debilitating symptoms and even death. Policies must be developed and implemented to prevent mTBIs and increased medical access for assessment and proper treatment post-injury, including vestibular and auditory rehabilitation. By improving medical access, this will help set patients up for the best recovery outcome after mTBI. The World Health Organization acknowledged the value of audiologists, speech-language pathologists, psychologists, physical therapists, and many more as professionals that may be important players in the rehabilitation process.

Quatman-Yates et al., (2020) provides a set of evidence-based clinical guidelines for physical therapists based on the American Physical Therapy Association guidelines on the diagnostic and management for the wide spectrum of patients who have experienced a mTBI. The American Physical Therapy Association recognizes the value of physical therapists as a part of the multidisciplinary team in treating patients with mTBI. There is a growing body of evidence to support the use of active rehabilitation strategies for post mTBI impairments and other vestibular disorders that occur due to mTBI. While managing mTBIs are within the scope of practice for physical therapists, the American Physical Therapy Association recommends that physical therapists who intend on treating patients with dizziness or vestibular effects and mTBI, seek specialized training. Physical therapists have the ability to screen, examine for a mTBI diagnosis, and evaluate for differential diagnosis, but patients that have complex cases, report dizziness or vertigo should have a full examination for cervical and spine dysfunction, vestibular, and oculomotor dysfunction and orthostatic dysfunction. Physical therapists have some tools to do these examinations such as vestibular ocular motor screening and Dix-Hallpike maneuvers but are advised to triage to other professionals, such as audiologists that can do full testing. Lastly, physical therapists that manage patients with mTBI should consider specialized training to deliver appropriate vestibular rehabilitation. Specialized plans should be developed based on the patient's symptoms. Vestibular rehabilitation aims to reduce vertigo and dizziness, improve gaze stability, and reduce imbalance or learn compensatory or habituation strategies with chronic balance problems. Just as physicians play a large role in the multidisciplinary team, specialized physical therapists also have a position on the team. The American Physical Therapy Association acknowledges the need for mTBI treatment but recommends appropriate diagnosis before treatment through referrals to better-equipped professionals like audiologists, and proper training when physical therapists treat patients with mTBI and vestibular dysfunction.

The Speech-Language and Audiology of Canada Association position statement recommends that treating mTBIs requires a multidisciplinary approach to provide the best quality of care, because audiologists are most specialized in assessing auditory and vestibular symptoms that can occur in post mTBI (Noel et al., 2019). Emerging evidence suggests that auditory evoked potentials may also be used to assess mTBI and therefore is another reason for the necessity of audiologists to be included in standard mTBI protocol (Noel et al., 2019). Hardin et al. (2021) recommends creating a mTBI protocol with an interprofessional team that specifically has experts in the field including both audiologists and speech-language pathologists as part of the assessment and management process.

The American Speech-Language-Hearing Association (ASHA) has not released one uniform position statement relating to mTBI; however, it has released many articles with evidence that both audiologists and speech-language pathologists should be included within the multiple disciplinary team approach. Multiple summary articles have been released on ASHA's website with ratings and recommendations from the Ontario Neurotrauma Foundation (2016, 2018) clinical practice guidelines which include diagnostic assessment, initial management, general management for prolonged symptoms, sleep disturbances, mental health disorders, cognitive difficulties, vestibular and vision dysfunction, fatigue, and return-to activity, thus emphasizing the need for the multidisciplinary team. Specifically, ASHA guidelines for audiologist's and speech pathologist's include evidence ratings and recommendations for mTBI management, including referring to audiologists with appropriate qualifications to treat audiological symptoms like hearing impairments, tinnitus, sensitivity to sound and vestibular impairments (American Speech-Language-Hearing Association, 1970). A large database is available on ASHA's website with articles about guidelines for pediatrics, legislation for student-athletes with sports-related concussions, systematic reviews on vestibular assessments, vestibular rehabilitation, hearing evaluations, and management. Based on the available resources, it is clear that although there is not a released position statement on mTBIs, ASHA believes that audiologists and speech pathologists should be a part of the multidisciplinary team.

Similarly, other professional organizations within the United States such as the Academy of Audiology, Academy of Doctors of Audiology, Military Audiology Academy, and many other professional organizations have not released a position statement in this area but have acknowledged that in certain situations assessment and rehabilitation of mTBIs are within the scope of practice and provided current research to support this claim through journal articles, educational sessions, and events. Due to the overlap between mTBI and auditory and vestibular systems, audiologists should be aware that assessment and treatment in this area are necessary and will likely become more common and expected within our field. In order for this to happen, it is vital that professional organizations take a stance on this issue and work with other professionals to make assessing and treating mTBIs a multidisciplinary approach. Based on the position statements and guidelines above, overall, many professional organizations within the United States acknowledge the audiologist's role in mTBI management. An example flowchart of when audiologists should be referred to can be found in Figure 1, followed by Figure 2 which explains audiology assessment after a referral.

Figure 1

Physician Referral to Audiology Flowchart

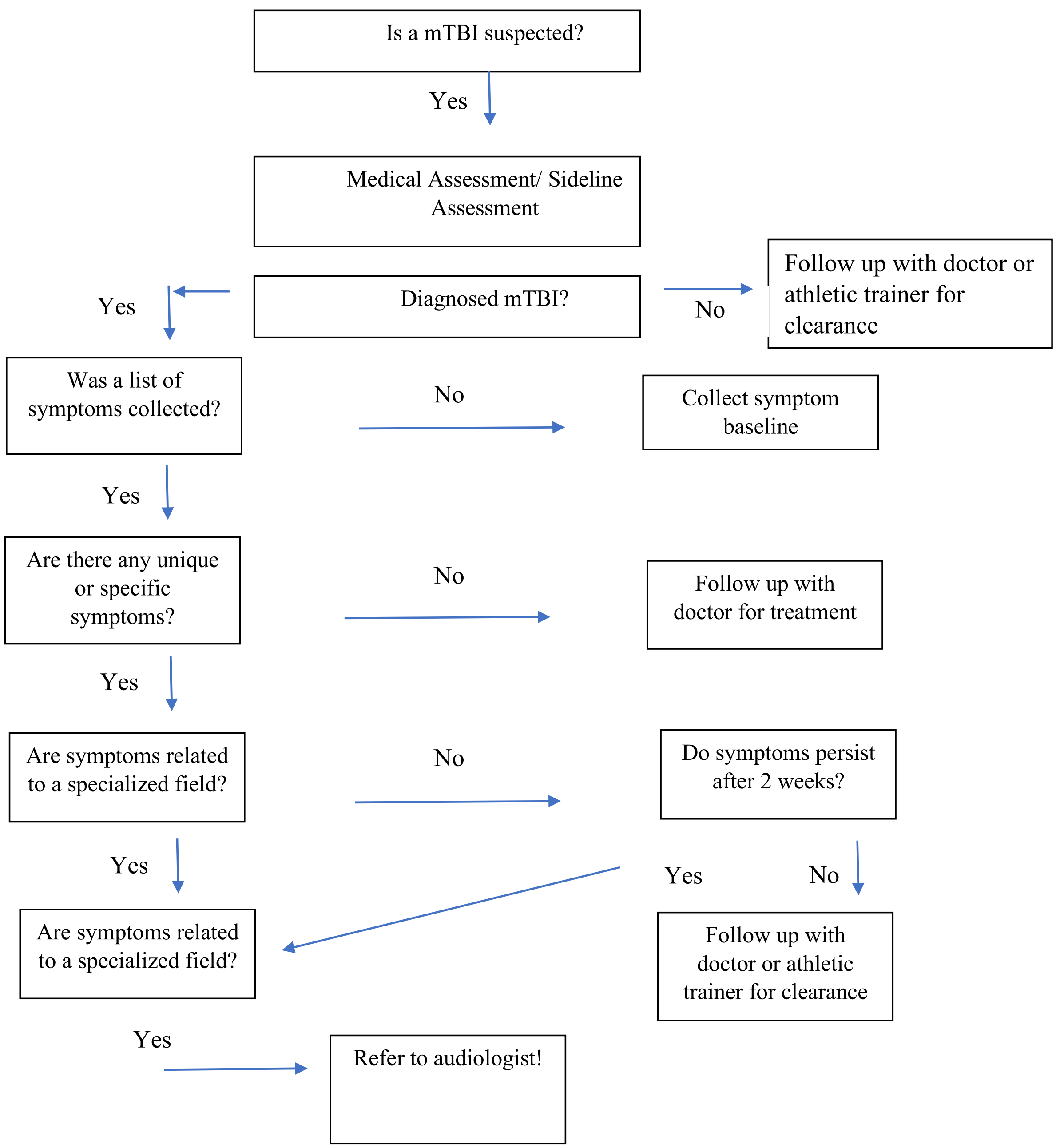
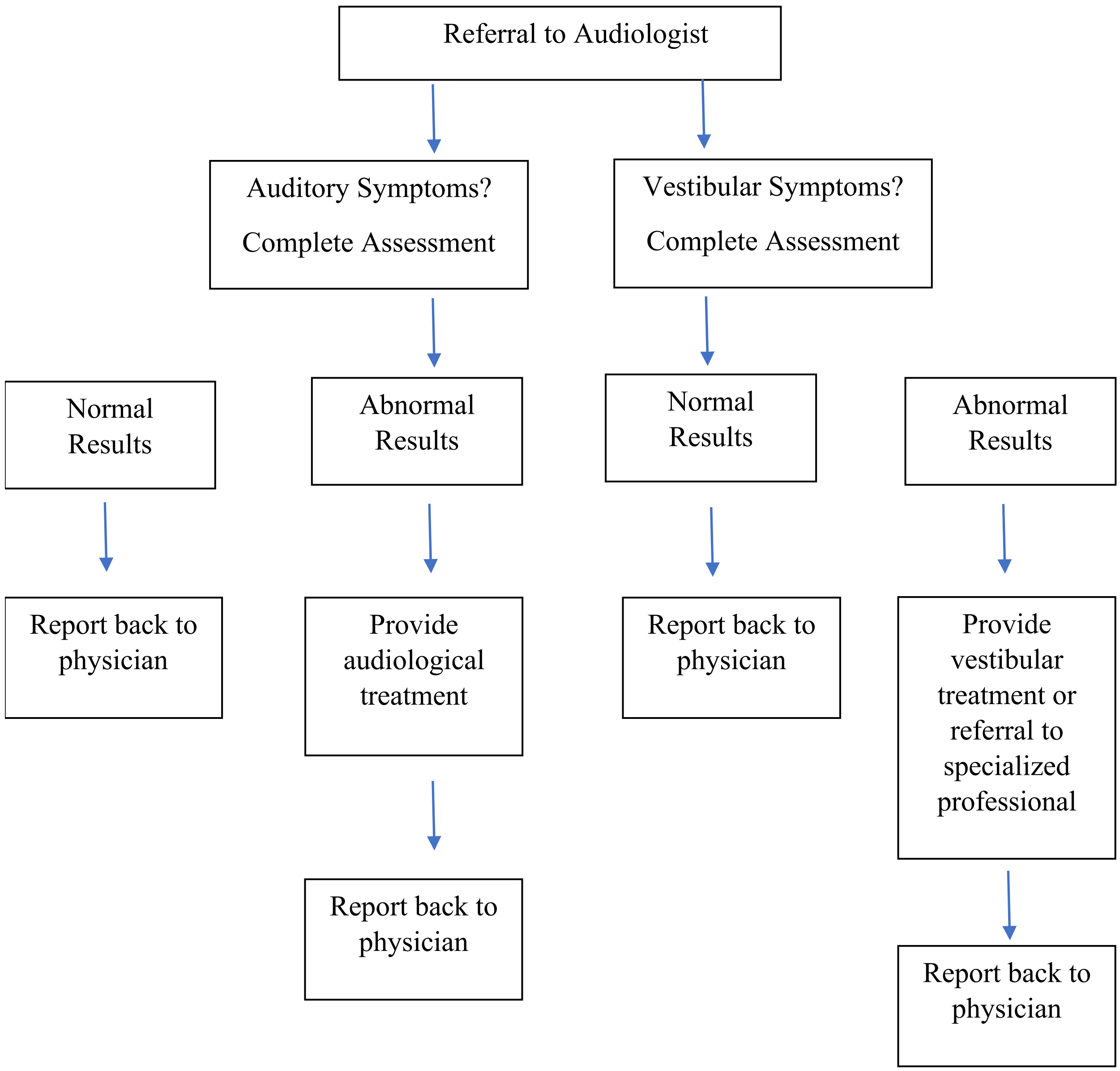


Figure 2

Audiologist Assessment Flowchart after Physician Referral



Audiologist's Role in Mild Traumatic Brain Injuries

Balance problems can stem from a facet of different disorders. They are often complicated because of the interaction between multiple systems and organs to maintain balance. Due to the complexity of the vestibular system and frequent presence of vestibular related symptoms in mTBI, the diagnosis and management of mTBI is difficult, therefore, patient management should involve different professions including otologists, audiologists, primary care physicians, athletic trainers, physical therapists, neurologists, ophthalmologists, pharmacists, psychologists, and more. Unfortunately, many patients don't receive a thorough evaluation from different specialty fields despite the benefits. The previous sections in this chapter addressed the scope of practice for audiologists, the prevalence and overlap in vestibular disorders and mTBIs, and the benefit and need for audiologists to be a part of a multidisciplinary team. This is all supported by recommendations and position statements from some of the largest and most influential professional organizations. The goal of this final section is to look specifically at the audiologist's role in mTBI.

With the correlation between different vestibular disorders and mTBIs, there has been a lot of research in online trade journals on the value of audiologists that have yet to be published in peer-reviewed journals. Whitelaw (2020) specifically addressed the audiologist's role in a mTBI in a 20-question interview with Dr. Mueller. Dr. Whitelaw addressed the diversity in the field of audiology from audiological evaluations, to fitting hearing aids, programming cochlear implants and bone-anchored implants, interoperative monitoring, newborn and children's screenings, and vestibular assessments. Dr. Whitelaw reports that she participates in a monthly support group for patients with mTBIs and their families. New members often seek Dr. Whitelaw as a resource to help address issues from dizziness, tinnitus, difficulty hearing in background noise, and much more. Many of those patients seeking help were discharged from a hospital or physician's office without any follow-up care related to post-concussive syndrome. Many patients are not referred until they have post-concussive symptoms multiple months down the road. Some patients that reported any auditory effects were sent to an otolaryngologist (ENT) office where they were told they had normal hearing and discharged. Patients with mTBI often have subtle symptoms related to audiology, especially with just a typical case history form, but sorting out audiological and vestibular symptoms and referring may significantly improve a patient's quality of life. Dr. Whitelaw recommends full auditory assessment with tympanometry and acoustic reflexes unless sound intolerance is suspected, speech in noise testing for auditory processing disorders, vestibular assessments, and even electrophysiological measures.

To begin a thorough evaluation on these patients, an in-depth case history is necessary. This case history will give the audiologist an opportunity to cater the appointment based on the unique complaints of the patient. The case history should include a normal case history form for the clinic to address any other hearing and vestibular concerns, as well as a case history form specifically for mTBIs. See Appendix A for an example case history form. Just like a case history for audiological problems like hearing or tinnitus, the case history form will provide detailed information on the date, length, severity of the problem, previous pertinent case history, symptoms, social history, and standardized symptom questionnaires. The standardized questionnaire may be the Rivermead Questionnaire or Post Concussion Symptom Questionnaire as stated in Chapter 1, perhaps a sleep questionnaire, and a questionnaire like the Dizziness Handicap Questionnaire. Audiologists cannot treat all mTBI symptoms, but they can pay attention to the symptoms that directly affect the auditory and vestibular system.

Once the detailed case history is completed, the audiologist must form a test battery. The purpose of a complete vestibular assessment is to identify where the problem is within the system and rule out other possible vestibular disorders sequela or co-founding to an mTBI. Complete vestibular assessment testing takes about two hours depending on the number of tests completed and how long the tests take. The goal of vestibular assessment is to get an overview of how the different parts of the vestibular system are functioning and add any additional tests, based on reported symptoms that may indicate a unique vestibular disorder. Some patients are not able to withstand the full testing; they may need longer breaks to let nausea subdue, nystagmus to calm down, or just fatigue from testing. Not all clinics will have a rotary chair or CDP equipment, which may also affect the time and tests completed. At minimum, the vestibular assessment should be able to assess whether the dizziness is of central or peripheral origin and how the vestibular and visual systems are working together, which is commonly assessed through VNG/ENG. VEMP testing can help assess the function of the saccule and utricle and the associated vestibular branches of the VIIIth cranial nerve.

Additional testing that may be completed at the appointment includes rotational testing, which is useful in understanding different frequencies and speeds that are affected. If episodic vertigo is suspected, it is important to do positional testing to test for BPPV. vHIT is recommended as a supplemental test to VNG/ENG and rotation tests because it assesses small, quick movement rather than slow or moderate speeds tested with rotational testing. If CDP is available, this test is useful in assessing balance and fall risks in athletes and elderly populations. If a PLF is suspected, complete a fistula test, and lastly, if SSCD is suspected complete a VEMP. Modifications may be made based on the patient’s case history and the results of the tests. As mentioned in the literature review, patients with mTBIs often have vestibular ocular motor impairments. The purpose of vestibular testing is to analyze the vestibular ocular reflex for any vestibular impairments and rule out or catch other vestibular disorders. If short on time and access to full vestibular testing equipment is available, a recommended test battery would be VNG, VEMP, positioning testing, and CDP to analyze all parts of the vestibular system, the VOR system, and balance since those assess areas most commonly affected by mTBI, however that test battery should be adapted based on case history. Audiological tests may also be necessary to incorporate if other symptoms such as hearing loss or tinnitus are a concern and if central vestibular problems are a concern. Brodsky et al. (2018) recommends looking at emotional dizziness, motion-induced dizziness, and migraine symptoms.

Prior to testing, there is a checklist of directions patients need to follow to ensure accurate results. The patient should have no eye make-up on and stop taking any medication that may interfere with the vestibular testing. The physician referring should let the patient know which medications to stop taking temporarily or a pharmacist, though there tends to be a grey area, so audiologists should also keep an eye out for medications on the case history that could influence testing. Some general medications and drugs to stop taking include vestibular suppressants, first-generation antihistamines, antiemetics, sleeping pills, caffeine, alcohol, marijuana, and tobacco. These drugs and medications are known to have effects on the vestibular system and may affect testing. Occasionally, patients will be on medications that would be life-threatening to discontinue which may influence the vestibular system. In those cases, the patient must stay on the medications, and the audiologists must document the results in relation to the medication.

It is within the scope of practice to do a complete assessment of vestibular function as audiologists, but so is the treatment of vestibular disorders. Many other professionals such as physical therapists, occupational therapists, and athletic trainers are most commonly involved in the management and treatment process, but some audiologists are trained in vestibular rehabilitation and therefore may be involved in the treatment process as well. As mentioned earlier in this chapter, it is essential to have a professional who has specialized in vestibular rehabilitation, no matter the profession. In some occupations, like physical therapy, substantial postgraduate training is required. For physical therapists, occupational therapists, and medical doctors, the gold standard is an in-person six-day course from Emory University. There are no prerequisites besides a professional degree, but it is recommended to have a working knowledge of the vestibular system. At the end of the course, the professional must be able to demonstrate proper skills and knowledge based on practice skills and written exams (Herdman & Clendaniel, 2010). Each profession will contribute different skills and knowledge to vestibular assessment and rehabilitation, so there is likely to be an overlap, therefore it is important to make appropriate referrals when necessary and communicate well as an interdisciplinary team.

There is a growing body of evidence to support the effectiveness of vestibular rehabilitation, for vestibular disorders and dysfunction from a head injury (Gurley et al., 2013; Gurr & Moffat, 2001; Mora et al., 2004; Wang et al., 2021). Successful rehabilitation is based on an appropriate diagnosis and targeted exercises on that diagnosis, such as BPPV which has above a 95% success rate with canalith repositioning maneuvers (Gans & Harrington-Gans, 2002).

Vestibular Rehabilitation Therapy (VRT) has two main goals: to enhance gaze stability and postural stability in order to improve vertigo and daily activities (Han et al., 2011). This is often done through repositioning maneuvers, adaptation, habituation, gaze stabilization exercises, and lastly, balance stabilization exercises. Vestibular therapy is typically personalized depending on the diagnosis and symptoms. Repositioning maneuvers to treat BPPV are an example of a targeted vestibular rehabilitation exercise based on a diagnosis. Adaption exercises are another form of vestibular rehabilitation that helps the patient modify the vestibular ocular reflex (VOR) response. Habituation exercises are repeated exposure to the provocative stimulus that will lead to a reduction in symptoms. These exercises are especially useful when people have dizziness during visually stimulating environments or patients who have dizziness when they move around. Gaze stabilization exercises are used to control eye movements during head rotation, once again focusing on the VOR and Cervico-Ocular Reflex. This type of training is best for patients who report visual problems, such as oscillopsia. The last type of vestibular rehabilitation is balance training to improve steadiness through adaptation exercises with and without somatosensory and visual cues. Improving the strength of the ankles and hips is an important part of balance training. VRT should be customized for each patient based on their diagnosis and patient input like goals or pain with certain exercises. Other factors to be aware of when developing a treatment plan is activity levels, medications, other medical conditions, and emotional concerns. Successful outcomes are common for peripheral disorders such as vestibular labyrinthitis or vestibular neuritis, MD, and SEH, but also for central disorders such as VM and PPPD. For these types of disorders, the patient is seen at least once a week for therapy sessions in addition to at-home exercises completed daily. Therapy may be more frequent at the beginning of treatment and less frequent as symptoms dissipate.

An emerging form of VRT is utilizing virtual reality. Virtual reality may add benefit to traditional vestibular rehabilitation because it can create stimulating or challenging environments that the patient may be exposed to outside the office, but under the supervision of a professional. Virtual reality may also be beneficial because it can improve rehabilitation access for patients who cannot travel to an in-person appointment or afford traditional vestibular rehabilitation. With the right equipment, virtual reality rehabilitation can take place anywhere, however, the patient must be trained properly on how to use the technology safely, whether that is virtually or through an introductory lesson in-person with follow-up training virtually. There is limited research available comparing the efficacy of virtual reality and traditional vestibular rehabilitation due to the lack of standardization in equipment set-up and outcome measures, however, available literature suggests that there may be a clinical benefit that is not only equivalent, but superior to conventional vestibular rehabilitation. Xie et al. (2021) completed a systematic review to determine the effectiveness of virtual reality in vestibular rehabilitation. Four out of six randomized control trials reported better subjective or objective outcomes in the virtual reality groups than in the conventional vestibular rehabilitation therapy groups. Two out of six randomized control trials reported better objective outcomes in the virtual reality groups. There was a large range of heterogeneity within each of the studies, so different diagnoses, assessments, and treatments were used in each study. Based on this information, more research is necessary before implementing virtual reality into a vestibular rehabilitation treatment plan and may require additional training in every profession.

Many professionals may perform vestibular rehabilitation, including audiologists. Audiologists are not required to get specialized training like physical therapists, because it is included as part of their graduate curriculum in the doctorate of audiology program, however additional training is highly encouraged as it is a unique part of the profession and rarely done by audiologists. In the future, audiologists may play a bigger role in vestibular rehabilitation and be referred to more than other professionals like physical therapists, especially if the patient already went through a vestibular assessment with an audiologist. Therefore, it makes sense to follow through with treatment and management from a professional that the patient already knows and trusts.

It is evident that audiologists have a role in managing mTBIs. To accurately diagnose and treat patients, a multidisciplinary approach to mTBI patient care including audiology may be beneficial. mTBIs can affect cognitive, visual, physical, auditory, and vestibular symptoms. Due to auditory and vestibular symptoms audiologists are the best resource to help patients with difficulties in this area. Since dizziness is one of the most common complaints it is hard to decipher where the dizziness is stemming from, therefore a vestibular assessment may be necessary. Not every patient will need assistance from audiologists, but that should be decided on a case-by-case basis. With support from the World Health Organization, AAA, ASHA, and the Speech-Language and Audiology Canada association, audiologists should be a part of a standardized multidisciplinary team.

CHAPTER III

CRITICAL APPRAISAL OF THE RESEARCH AND FUTURE DIRECTIONS

Gaps in the Literature

Existing literature provided groundwork for the investigation of the audiologist's role in evaluating and managing patients with mTBIs and vestibular disorders. There is a growing body of research on vestibular dysfunction following a head injury, however, there is still a need for more research and development on previous research to better understand traumatic brain injuries (TBIs), the etiology, type of injury, severity, how to treat patients with post-traumatic dizziness, and prevalence of vestibular disorders secondary to mild Traumatic Brain Injuries (mTBI). A summary of the limitations within the literature and future directions are addressed in this chapter.

Mild Traumatic Brain Injury
Diagnostic Criteria

Many studies use different definitions and guidelines that impact the results of the studies and make it difficult to compare results across studies. In Chapter 1, different traumatic brain injury definitions were established from a penetrating injury to mild traumatic brain injury (mTBI) or concussion, and contusion. This doctoral scholarly project focused on vestibular effects secondary to mTBIs, however in the research presented, different research studies utilized different definitions and it was important to pay attention to terminology to avoid looking at TBI research that was unrelated to mTBI.

The definition of a TBI was found to vary between different professional organizations and published guidelines. Apps and Walter (2012) reported over 25 grading systems with different criteria, such as the Colorado Medical Society which has three severity levels based on loss of consciousness time and amnesia time. The Academy of Neurology has similar severity levels, but also accounts for symptoms present after a traumatic event. This is just an example of two out of the 25 grades that differ in the classification of mTBIs. Due to the differences in diagnosis severity grades, there is a wide range of heterogeneity, again, making it difficult to compare and contrast studies and draw conclusions. When reviewing the literature, researchers did not explicitly report which diagnostic grading system they utilized. Rather, vague diagnostic descriptions such as 'a blow to the head causing the person to stop what they were doing' were reported. Many studies limited the participant sample based on where or how the participants were injured, such as in sports, car accidents, or work-related injuries. Some larger studies pooled data from several different individual studies that may have used different definitions of mTBI and severity grades, therefore it is important to analyze each study carefully to ensure that type of injuries were accounted for. At a minimum, results from athletic-related injuries compared to falls or work-related injuries should be reported and evaluated separately.

Not only are there differences in definitions, diagnostic criteria, and the severity of injury, but the type of assessment tool utilized may influence results. Computed tomographic (CT) scans and magnetic resonance imaging (MRI) scans are occasionally used to help diagnose mTBI; however, they do not provide a lot of added benefit to diagnosing mTBI and the severity. In the future, imaging tools may provide enough objective evidence to create a diagnostic and severity criterion that is universally accepted. Instead, screening and assessment tools are used to diagnose mTBI. Some assessment tools are based on self-reported symptoms, while other tools will use a physical test that assesses skills, such as motor skills, oculomotor function, and memory. Some of the most common assessments utilized are the Glasgow Coma Scale, Rivermead Post Concussion Symptom Questionnaire, Standardized Concussion Assessment Tool (SCAT), Immediate Post-Concussion Assessment, and Cognitive Testing (ImPACT). There is not one assessment tool that has the sensitivity and specificity to properly identify mTBI in isolation, therefore it is recommended to utilize multiple assessments that analyze symptoms, neurocognitive functioning, and balance. It is best practice for authors to specify which diagnostic criteria and assessment tools were utilized in their study, so the audience can carefully critique the quality of the article. Case studies and randomized control trials may report diagnostic criteria or assessment tools, however, it is important to carefully evaluate studies that compare and review multiple articles such as meta-analyses and systematic reviews, since individual studies within may be following different criteria. It is very important to understand the type of assessment and diagnostic criteria for each study before comparing results to ensure that comparisons are appropriate and equitable. Different definitions of mTBI, diagnostic criteria, severity grading scales, and assessment tools limit the validity and the ability to properly compare studies, therefore, in the future, uniform definitions, diagnostic criteria, and severity scales should be implemented.

Education

Vestibular assessment and rehabilitation have been included in the audiologist's scope of practice for over 20 years, however, only a small portion of time is spent on vestibular audiology education. Through a review of different program websites, most clinical doctorate degrees require only one course on vestibular assessment and management. However, due to growth in the field of vestibular audiology, a handful of schools are providing more than just one dedicated course. Nova Southeastern University requires seven to ten credits of vestibular training for all Au.D. students. Salus University requires a total of six credits in vestibular training for all Au.D. students, but also offers an Advanced study certificate in vestibular sciences, in which students who are interested in vestibular audiology complete an additional three credits (Salus University, n.d.) Similarly, Vanderbilt University requires all Au.D. students to take two vestibular courses, but also offers a vestibular specialty track which requires those students to take an additional one or two courses along with research and a practicum session focused on vestibular audiology (Vanderbilt University, 2021).

Nelson et al. (2016) conducted a survey to ask audiologist's opinions on if vestibular assessment and rehabilitation are within the audiologist's scope of practice and how prepared audiologists feel to conduct vestibular assessments and vestibular rehabilitation and 89% of respondents felt that audiologists are the most qualified professionals to conduct vestibular assessments. However, when audiologists were asked if they felt prepared to do vestibular assessments with just graduate training, only 44% of respondents agreed. These findings suggest a need for improved graduate training and perhaps more educational training opportunities with continuing education credits so that audiologists are recognized as the best profession to perform vestibular assessments. In terms of vestibular rehabilitation, only 9% of respondents felt prepared to provide this service following their graduate coursework and acknowledge that audiologists may not be the best professionals to provide vestibular rehabilitation. Graduate coursework should include understanding the anatomy and physiology of the vestibular system, vestibular pathologies, assessment strategies, how to put together a strong test battery, proper training on how to use equipment, how to analyze results, and make recommendations, whether that is making appropriate referrals or how to do vestibular rehabilitation. Many of those topics mentioned are covered across multiple courses throughout a graduate program, however, a dedicated vestibular course to those skills is necessary. Post-graduate training and certificates to show documentation of training to other professions may be valuable to audiologists who want to specialize in vestibular audiology including vestibular rehabilitation. The American Institute of Balance offers continuing education credits and additional certification to audiologists, physical therapists, medical physicians, nurse practitioners, physician assistants, occupational therapists, and athletic trainers (The American Institute of Balance, n.d.). The American Institute of Balance offers a course in vestibular assessment and management, vestibular rehabilitation, pain management, and concussion assessment and rehabilitation. Audiology Online also offers continuing education courses that were developed to help audiologists feel more prepared for vestibular assessment and management. By improving graduate training, post-graduate continuing education credit opportunities, and offering vestibular certificates, audiologists will be better prepared and recognized as the most valuable profession to perform vestibular assessment and management.

When it comes to working with mTBI patients, there is a communication gap and a lack of interdisciplinary care between professions. Multidisciplinary teams are the best way to ensure that patients with mTBIs get proper assessment and treatment. Audiologists should be involved in a multidisciplinary team along with otolaryngologists, primary care physicians, neurologists, physical medicine and rehabilitation doctors, athletic trainers, physical therapists, and/or ophthalmologists to ensure that patients get the proper assessment and treatments. To bridge this gap, it will be important for professional audiology organizations like the American Academy of Audiology to release a uniform position statement that addresses vestibular management and treatment secondary to mTBI and work closely to educate other professionals about the connection between mTBIs secondary to vestibular disorders.

Lack of Epidemiology Data

Research in the field of mTBIs and the vestibular system is growing quickly, but at this point in time, research is still limited. Finding the epidemiology of mTBIs alone is difficult. Thurman et al. (1999) released a report to the American Congress on the prevalence of mTBIs, reporting about 1.5 million Americans annually with 230,000 hospitalizations, 50,000 deaths, and 80,000-90,000 long-term disabilities. These statistics are over 20 years old and therefore outdated. Hospitalizations and deaths due to TBI have been updated, but overall prevalence has not been formally reported. The epidemiology of mTBIs is extremely difficult due to heterogeneity with definition, and diagnostic criteria, and only about 10% of patients are hospitalized (Leo & McCrea, 2016; Lo & Tanner, 2013). Many patients who experience mTBI may not visit a doctor or see just an athletic trainer which may lead to inaccurately reported statistics. Peterson et al. (2019) reported about 223,000 hospitalizations and about 60,000 TBI-related deaths which are similar to the statistics from Thurman et al. (1999). Variable reports have been noted in the literature for an overall prevalence of anywhere from 1.6 to 3 million Americans a year (Greenwald et al., 2012) and 42 million worldwide (Gardner & Yaffe, 2015). These numbers are estimations and may be higher due to unreported injuries.

Correct vestibular diagnosis separate from a mTBI can also be difficult. Disorders such as Meniere's disease (MD), secondary endolymphatic hydrops (SEH), benign positional paroxysmal vertigo (BPPV), and enlarged vestibular aqueduct disorder (EVA) have distinct diagnostic criteria. Other disorders such as perilymph fistulas (PLF), superior semicircular canal dehiscence (SSCD), vestibular migraine (VM), labyrinthine concussion, persistent postural-perceptual dizziness (PPPD), are disorders diagnosed based on exclusion. Prevalence data is reviewed in more detail in Chapter 2; however, much more research is necessary to understand the prevalence of each individual vestibular disorder.

Since it can be difficult to individually diagnose mTBIs and vestibular disorders alone, finding the prevalence of vestibular disorders secondary to mTBIs is even more challenging. Few studies report prevalence which are often based on small sample sizes. There is a large range between the studies that do report prevalence. Literature reports anywhere between 14-90% based on the different criterions utilized (Skóra et al., 2018). As stated in Chapter 2, some disorders such as PLF, SSCD, and EVA may be present, however, some patients may not present symptoms until a head injury. In the future, larger, high-quality articles will be valuable to get a better understanding of the overlap between mTBIs and vestibular disorders. More research on the prevalence between mTBIs and vestibular disorders will help provide justification for audiologists to be a part of the multidisciplinary team and will be useful when educating other professionals such as medical doctors, athletic trainers, physical therapists, and ophthalmologists.

One thing to note is that a large portion of the research available is focused on adult populations. There is a limited amount of research on children with vestibular disorders secondary to mTBIs. Children are at risk for complications from mTBIs, so it is important that children also get appropriately assessed. Ghai et al. (2019) reviewed the literature and found three articles that reported anywhere between 14.1-81% of children with a mTBI also have vestibular dysfunction. This is a large range because there is very limited data, however, this data is not far off from the reported prevalence of vestibular disorders secondary to mTBI in the adult population. Not only is there limited and highly variable data reviewed in the literature, but there is no normative data for children who go through vestibular assessments nor a standardized approach to pediatric vestibular testing. Future research needs to also address the impact of vestibular disorders secondary to mTBIs on the pediatric population as well as adults.

Future Recommendations

As stated previously, it will be necessary to get better data on the epidemiology on mTBI and vestibular disorders, before it is possible to fully understand the overlap between the two as well as more specific guidelines for diagnosing both mTBI and vestibular disorders. Current research does demonstrate a relationship between vestibular disorders secondary to mTBI, therefore it will be important to educate all professionals about this research. Though the prevalence of a vestibular disorder secondary to mTBI is low, those few patients that do not receive the correct assessment and treatment suffer from long-term consequences that may have been avoided. See Figure 2 for a flowchart on making proper referrals, Appendix A for a case history form for patients to fill out at an audiology appointment and the case study in Chapter 2. Patients who experience dizziness deserve the best service to help accurately diagnose and treat the problem.

Preparing audiologists within graduate training programs and providing continuing education opportunities will be beneficial to make sure that audiologists are not only comfortable completing assessments but be the best professionals to assist with assessments and perhaps even rehabilitation. In order for this to be possible future research needs to be directed toward making universal standards for vestibular test batteries and diagnostic criteria for each vestibular disorder.

Many audiology offices are beginning to advertise and provide vestibular services along with audiological services to patients with mTBIs, however, a larger support base from professional audiology organizations may help expedite this process. The American Academy of

Audiology (AAA) and American Speech-Language-Hearing Association (ASHA) recognize the problem and have released articles based on trade journals, such as Audiology Today and the ASHA Leader on their websites. However, releasing a uniform position statement or adding to the scope of practice will help validate the audiologist's role in being a part of the multi-disciplinary team diagnosing and rehabilitating mTBIs and vestibular disorders from the audiology professional's side. In order for audiologists to always be a part of that multidisciplinary team, it will take professional organizations to educate other professionals such as primary care physicians, ENTs, physical therapists, athletic trainers, and ophthalmologists. It is not unusual for ENTs to refer to audiologists for anything that may be vestibular related, due to understanding the audiologist's specialty as well as many audiologists reside in the same office as ENTs making referrals seamless. The American Physical Therapy Association recognizes the need for mTBI treatment through vestibular rehabilitation but recommends appropriate diagnosis before physical therapists perform treatment, so unless the physical therapist is certified in vestibular dysfunction the American Physical Therapy Association recommends referrals to better-equipped professionals like audiologists. Building these connections between the different professionals and organizations will increase accurate diagnosis and treatment. Professionals such as primary care physicians, athletic trainers, ophthalmologists, and neurologists need to be better informed on the value of audiologists in the assessment and management of mTBIs so that appropriate referrals are made as well as education on standardized diagnostic criteria, screening, and assessment protocols.

Summary

Research demonstrates that there is a connection between vestibular disorders after mTBIs (Brodsky et al., 2018; Fitzgerald, 1996; Noel et al., 2019; Skóra et al., 2018). Despite this connection, audiologists are not always included on the multidisciplinary team for assessing or rehabilitating persistent dizziness after mTBIs that may be related to the vestibular system. Through the appraisal of existing literature and future recommendations, it is evident that there is a need for audiologist's skills, however, there are extensive gaps in literature and research that are a barrier for routine inclusion of audiologists on a multidisciplinary team. Through this doctoral scholarly project, it is evident that audiologists can play a valuable role in diagnosing and managing vestibular disorders secondary to a mTBI to help each patient get the best care possible.

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APPENDIX A

MILD TRAUMATIC BRAIN INJURY/ CONCUSSION

CASE HISTORY FORM

mTBI/Concussion Case History

Name: ______________________________ Date: ______________________________

Birth date: ___________________________ Age/Grade: ___________________________

Gender: ______________________________ Phone Number:________________________

Email: ______________________________

Address: ____

Referred by: ____

Emergency Contact Name: ____

Phone Number: ____

Injury Information

Please answer all the following questions about your concussion to the best of your ability.

Date of Injury: ____

Cause of Injury: ____

Do you remember all the events before, during, and after injury? Y or N

If yes, describe events leading up to the incident? ______________________________
____

If yes, describe events after the incident? _____________________________________
____

Did you lose consciousness? Y or N

If so, how long? ____

Were you hospitalized? Y or N

Did you have imaging completed? Y or N

Who are the providers that are involved in managing your injury? (i.e Primary care physician, athletic trainer, ENT, neurologist, optometrist, Physical therapist, Emergency room doctor)_____
____
____
____

Have you had any previous concussions or other neurological events? Y or N

If yes, please list date and cause of injury/injuries: ____________________

____

____

Did you have full recovery? Y or N

Has your living situation changed since your injury? Y N N/A

If yes, please describe: ____________________

____

____

Work difficulties? Y N N/A

If yes, please describe: ____________________

____

____

School difficulties? Y N N/A

If yes, please describe: ____________________

____

____

Have your hobbies changed since your injury? Y N N/A

If yes, please describe: ____________________

____

____

Background Information

Circle all that apply prior to injury:

Headaches	Migraines	Vision Problems
Glasses or Contacts	ADHD	Depression
Anxiety	Other Mood Difficulties	Sleep Difficulties
Learning Difficulties	IEP	504 Plan
Poor Grades	Occupational therapy	Speech Therapy
Developmental disorders	Stroke	Seizures
Cervical Spine Arthritis	Macular Degeneration	Ataxia
Parkinson’s Disease	Multiple Sclerosis	Neuropathy

If you circled any, please provide more detail (including medications if any): ________________
____

Vestibular History

Do you feel dizzy? Y or N

Do you feel lightheaded? Y Sometimes N

Do you feel like you are spinning, or the world is turning around you? Y Sometimes N

Do you feel unbalanced when you are stable? Y Sometimes N

Do your symptoms cause you to feel nauseated or vomit? Y Sometimes N

Do you feel tingling in your hands/feet? Y Sometimes N

Date of symptom Onset?

Sudden or Gradual

Constant or Variable

If variable, please answer the following questions-

How often do the dizzy/vertigo episodes occur? _________Minutes/hours ____________days ____________Weeks ____________months

How long do the dizzy/vertigo episodes occur? __________Minutes/hours ____________days ____________Weeks ____________months

Does anything happen leading up to the episode? ______________________________________

Do your symptoms change with positions?

Does looking up worsen the symptoms? Y Sometimes N

Do quick movements worsen the symptoms? Y Sometimes N

Does turning over in bed worsen the symptoms? Y Sometimes N

Does turning head to drive worsen the symptoms? Y Sometimes N

Does bending over worsen the symptoms? Y Sometimes N

Does sitting/laying down to standing worsen symptoms? Y Sometimes N

Does coughing, sneezing, blowing nose worsen symptoms? Y Sometimes N

Does stress worsen symptoms? Y Sometimes N

Do loud sounds worsen symptoms? Y Sometimes N

Do large crowds or busy environments worsen symptoms? Y Sometimes N

Does physical activity worsen or improve symptoms? Y Sometimes N

Does diet worsen or improve symptoms? Y Sometimes N

Does time of day worsen or improve symptoms? Y Sometimes N

Please describe any other movements that worsen your symptoms ____________________

____

____

Was it associated with a head injury? Y or N

Have you fallen as a result of your symptoms? Y N

Is there anything that makes the dizziness better? Y or N

If yes, please explain____

____

____

Social History

Do you drink caffeine? Y Sometimes N

How many cups per day/week/month?____

Do you smoke/chew tobacco? Y Sometimes N

How many per day/week/month?____

How many years?____

Do you drink alcohol? Y Sometimes N

How many glasses per day/week/month? ______________________________________

Do you have any recreational drug use? Y Sometimes N

I use____

How many times per day/week/month?____

How many years? ____

Do you take any medications? (ex. Meclizine, Ativan)

How often?____

What are you hoping to accomplish from this appointment?________________________________
____
____

Is there anything else you would like us to know? ____
____
____

_______________________________________ ___________________________

Patient Signature **Date**

I have reviewed my case history and there have not been any changes.

_______________________________________ ___________________________

Patient Signature **Date**

*****Include PCSS or Rivermead Post concussion symptom questionnaire and DHI

Based on Vestibular Association, Newton Wellesley Hospital, Providence St. Mary's hospital