Disorders of the vestibular system result from damage to either the peripheral or central system that regulate and control our ability to balance. These disorders can lead to symptoms like dizziness, decreased balance, proprioception problems, vision changes, vertigo or hearing changes. Damage to the vestibular system from either direct injury or a disease process can elicit any of the listed symptoms. Research has shown a trend towards a widespread problem affecting the general population. Agrawal, Carey, Santina, Schubert, and Minor (2009) found, in a national sample of adults ages 40 and over, that 35 percent of individuals tested positive for vestibular dysfunction. This outcome has widespread implications for those individuals who reported dizziness because the odds of falling increased 12-fold. The implications for sustaining a brain injury are obvious—the Centers for Disease Control and Prevention reports that 35 percent of all traumatic brain injuries are the result of falls, which disproportionately affect children and older adults. Ironically, vestibular issues also present as common symptoms after brain injury, including both dizziness and balance deficits.

Balance is one of those vital functions we often take for granted, unless we suddenly find that our balance is not quite like it used to be. Balance problems can lead to a myriad of functional problems and can lead to safety issues, which can require ongoing assistance if left untreated. Balance requires coordination of a variety of systems in order to work optimally. Should any of these systems become affected, balance problems or other symptoms can lead to functional issues. There are four systems we use for balance: musculoskeletal, somatosensory, vision and vestibular.

**Musculoskeletal system**—Normal function in lower extremities and trunk significantly contributes to good balance. Conversely, when there is a lack of range of motion and strength in these areas, balance can be adversely impacted. Rehabilitation to counteract weak muscles and stiff joints through strengthening programs and stretching exercises can greatly improve balance.

**Somatosensory system**—This refers to both proprioception (or one’s own perception of themselves in space) and sensation, especially on our feet. The somatosensory system can be affected by a variety of conditions, such as neurological insult, diabetes, peripheral neuropathy or poor circulation. Like the musculoskeletal system, clinical intervention can counteract problems with this system thereby improving one’s sense of space and sensation leading to improved balance.

**Visual system**—When a person sustains a brain injury and their visual system is affected, it can make balance regulation difficult. Additionally, this system can fail as we age, which can be a contributing factor to higher rates for morbidity and mortality in older individuals due to falls. In fact, balance-related falls account for half of accidental deaths in the elderly (Murphy, 2000). Gaze stabilization exercises, smooth pursuits and other visual exercises can improve this system and facilitate improved mobility in our environment and reduce the risk for falls.

**Vestibular system**—This system consists of the inner ear and the connection with the central nervous system. It is the sensory system that contributes the most information about movement, balance and a sense of spatial orientation. The vestibular system plays an important role in our ability to safely navigate through our environment. If damaged, it could be a
main reason for balance difficulties.

The vestibular system can sustain direct damage as a result of brain injury, which can lead to damage at a central level (the brain level, which impacts processing of information) or peripheral level (the sensory and motor nerve level, which impacts sensation or movement). The end result of such damage is that a person may have symptoms of dizziness, problems with proprioception or experience balance problems. In order to understand how damage to the vestibular system results in these symptoms or disorders, it is crucial to understand the basic anatomy and function of this extraordinarily complex system.

VESTIBULAR SYSTEM ANATOMY
The vestibular system provides us with three basic functions: sensory ability, which detects head movements; central nervous system processing, which gives feedback regarding body orientation; and motor output to our body to correct eye, head and bodily positions (Hain and Helminski, 2007). The processing of information from the sensory aspects of the vestibular system provides us with three very important reflexes: the vestibular ocular reflex (VOR), which keeps eye movements stable while the head moves; the vestibulocollic reflex (VCR), which keeps the head stable; and the vestibulospinal reflex (VSR), which stabilizes bodily movement, impacting posture and balance.

The basic anatomy of the vestibular system includes the inner ear, which is located within the temporal bone and contains three parts:
1. The cochlea—the aspect responsible for hearing
2. The vestibule and the semicircular canals (anterior, posterior and lateral)—responsible for sensing rotational movements of the head
3. The membranous labyrinth (sacs and ducts)—consists of the utricle, saccule and the semicircular ducts, and is responsible for sensing accelerative movements of the head

The membranous labyrinth contains a gel-like fluid as well as hair cells. These hair cells within both the utricle and saccule have “crystals” or sensory receptors on top of them. When our head moves, the gel-like fluid flows over the top of the crystals, which results in the tiny hairs bending. These tiny hair sensors detect the direction in which the hairs are bent and turns that information into neural output. This neural output provides information to our central nervous system, via innervation of Cranial Nerve VIII, and results in the initiation of the VOR, VCR or VSR as appropriate. Collectively, the components of the vestibular system provide us proprioception through sensing head movements and the resulting central nervous system processing of that information, as well as the motor output to correct body positioning, via the three reflexes, if central processing finds our body positioning in need of adjustment. This amazing system provides us with rapid sensation detection, neural processing and corresponding motor output, which then gives us the ability to maintain balance and understand where we are in space. So what happens when any of these functions no longer work properly?

Vestibular Dysfunction
The vestibular system and the central nervous system work together to help us control our eye, head and body movements to maintain balance. When there is injury to the brain, including injury directly to the temporal lobe, or other traumatic injuries that result from rapid acceleration or deceleration of the head, vestibular dysfunction can result. The key to effective treatment of these disorders is effective evaluation to identify the root cause of symptoms.

VESTIBULAR SYSTEM ASSESSMENT
Evaluation of balance issues after brain injury involves differential diagnosis to determine the cause of the individual’s deficit. This requires sequential ruling out of causes to get to the root cause. Areas to assess include the patient’s:
1. Health history
2. Strength and range of motion
3. Sensory systems
4. Visual system
5. Vestibular system

Health History
Obtaining a good health history from the patient, including the mechanism of their brain injury, the areas of the brain that were affected, and a detailed understanding of when the symptoms occur, will assist in an accurate diagnosis. It is important to have the patient describe what they are experiencing: spinning, off balance, light-headedness, nausea

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Common Vestibular Disorders

<table>
<thead>
<tr>
<th>Disorder</th>
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<tbody>
<tr>
<td>Benign Paroxysmal Positional Vertigo (BPPV)</td>
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<tr>
<td>Labyrinthitis</td>
</tr>
<tr>
<td>Perilymph Fistula</td>
</tr>
<tr>
<td>Ménière’s disease</td>
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<tr>
<td>Vestibular Neuronitis</td>
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or the sensation of motion. This provides useful information when beginning an evaluation. For example, if the patient states that the room spins every time they roll to their right side, this would be an indication of BPPV (see sidebar). If the person states that they feel light-headed every time they stand up, this could be indicative of orthostatic hypotension (rapid drop in blood pressure), which is a non-vestibular medical issue.

**Strength and Range of Motion**
Adequate strength in our lower extremities and trunk is crucial to maintain posture and balance in standing, and with ambulation. If there are deficits in these areas, strengthening exercises will be needed to allow for timely responses when balance is disrupted. A thorough evaluation of a person’s available range of motion (ROM) in their lower extremities is important because we use balance strategies at our hips and ankles when we lose our balance. For example, if someone was pushed backward, their feet would come up off the ground. This requires active dorsiflexion beyond neutral and is called an ankle strategy. If someone were pushed even harder, they would react with their hips. Balance strategies assist in maintaining balance and are dependent on proper ROM in the hips and ankles.

**Sensory Systems**
The sensation on the bottom of the foot can be assessed with a Semmes-Weinstein Monofilament. Five different spots are tested and recorded as either positive or negative. Proprioception also needs to be evaluated. There are many disease processes that affect the sensation in our feet, and it is an important system that assists in balance. Consider walking on a nature trail with wood chips and tree roots along the trail. As one is walking, their foot lands on a tree root that is covered with wood chips and their foot starts to roll to the side. If the person is experiencing impaired sensation on the bottom of the foot, along with reduced proprioception, their reaction may be delayed and could result in a fall or a twisted ankle.

**The Visual System**
Vision is an important system that assists with balance and should be evaluated. In particular, the VOR should be assessed, as it is can be a key indicator of BPPV. When testing a patient’s visual system, the eyes should move in the opposite direction as the head during rotational or translational movement. The vestibular system sends signals to the VOR. To simplify, head rotation stimulates the semi-circular canals in the inner ear. Impulses are sent to the brain via the vestibular nerve (VIII). These impulses travel to the brain and stimulate the nerve that supplies the muscles to the eyes.

Part of the assessment is to evaluate the VOR, as well as other oculomotor movements. The tests include: smooth pursuit, saccades, VOR slow, VOR rapid, head thrust and spontaneous nystagmus. These tests can help indicate whether it is a central or a peripheral level problem (positive VOR).

**The Vestibular System**
Once it has been determined that the vestibular system is involved, it is important to complete a vestibular evaluation. This consists of several different components. A good place to begin is with the Motion Sensitivity Quotient. This will give the clinician a good idea on what positions provoke the symptoms. There is also the ABC Confidence Scale that rates how confident a person is in performing different functional activities as it relates to their balance and risk for falls. Interestingly enough, some patients rate themselves very confident when they had poor balance and were at high risk for falls.

Assessment of oculomotor movements, including smooth pursuit, saccades, VOR and nystagmus (spontaneous or with the VOR), will indicate if the visual system is working, specifically regarding balance. A positive VOR is indicative of vestibular involvement, which will then lead the clinician to perform maneuvers to evaluate and possibly treat canal
involvement in the inner ear system. It is important to do a vertebral artery screen prior to performing these maneuvers. The Dynamic Gait Index (DGI) is a tool that can determine vestibular involvement by having the patient perform head movements while moving through their environment. The clinician looks for speed, smoothness of movement and loss of balance while they perform the different tasks.

The Clinical Test of Sensory Interaction on Balance (CTSIB) is a test in which the patient, with a dome over their head, stands on different surfaces first with eyes open and then with eyes closed. It is commonly referred to as the “foam and dome” test. At Rainbow, the Modified CTSIB is used because fewer positions are tested and a dome is not placed on the patient’s head. The modified test consists of the person standing on a firm surface with eyes first opened and then closed, and again on a foam surface-with eyes first opened and then closed. The goal is for the person to hold each position for 30 seconds. Each of the positions correlates to a different system that is more active in balance. For example, when someone is standing on foam with their eyes closed, the vestibular system is more active in balance and the somatosensory and vision systems are not.

Once the evaluation is completed, the canals are cleared (in the case of BPPV) and the clinician and patient can move into treatment techniques to get the system stronger, and improve the patient’s balance and reduce their risk for falls.

VESTIBULAR SYSTEM TREATMENT

When injury occurs to parts of the vestibular system, the brain is not getting accurate information to help regulate balance and equilibrium. If this system does not compensate for the deficit, the person will end up becoming more dependent on the other systems (musculoskeletal, somatosensory and vision) for balance. When all of these other systems are affected, the person is at risk for impaired mobility and is at very high risk for falls.

The purpose of vestibular therapy is to retrain the brain to recognize signals from the vestibular system and work collaboratively with vision and proprioception. Desensitizing of the abnormal vestibular response may need to occur along with strengthening exercises for gaze stabilization.

If the person has BPPV, it is important to make sure there are no crystals blocking the flow of the fluid within the ear. This can be done by performing a Dix-Hallpike maneuver (a vertebral artery screen needs to be done prior to performing this maneuver). If the Dix-Hallpike yields a positive result as evidenced by nystagmus, nausea and possible vomiting, the clinician will perform the Epley maneuver to “clear” the canal. Once the canal is cleared as evidenced by a negative Dix-Hallpike maneuver, the clinician can begin to work on habituation exercises and desensitizing movements to improve the function of the system that was not working. See box (page 17) for more information about these maneuvers.

The goal is to facilitate the compensatory process by incorporating exercises that include head movement with eye stabilization, head movement with eye movement, habituation exercises (Brandt-Daroff) to retrain and help the vestibular system to adapt, balance tasks that require the weakest system to be strengthened, strengthen hip and ankle balance strategies, and relaxation exercises.

CASE STUDY

A patient who unknowingly had BPPV was unable to leave her apartment by herself due to her lack of confidence in her balance. She was unable to stabilize her eyes and therefore could no longer read because the words appeared to be jumping all over the page. To see her walk on the sidewalk, one may think she was under the influence. After BPPV was diagnosed, evaluated and treated, she was able to read again and walk safely with confidence in her community.

Treatment Efficacy

Simoceli, Bittar and Sznifer (2008) looked at the difference between classic vestibular rehabilitation and adaptation of the VOR in an elderly population. In this study, they found that VOR exercises were easy for elderly adults to perform and that outcomes were similar between classic vestibular rehabilitation and VOR adaptation.

There are several articles related to blast injuries in soldiers with resultant traumatic brain injury where there was an associated vestibular pathology. Vestibular rehabilitation appears to be warranted in this population, however, there have been limited studies on this subject. Scherer and Schubert (2009) found that dizziness, along with vertigo, gaze instability, motion intolerance and other peripheral vestibular symptoms were common complaints of the soldiers returning home. The article stated that 32 percent of soldiers wounded since January 2003 have been diagnosed with a TBI. The conclusion of the article is that due to the nature of the complex polytrauma injury with a soldier, the vestibular injury is being overlooked and not addressed. When interventions
are done, including gaze stabilization exercises, habituation exercises (decrease hypersensitivity of provoking motions), static and dynamic balance exercises on varying surfaces, and canalith repositioning maneuver (getting crystals out of canal), good results are obtained as evidenced in improved evaluation and confidence scores with movement.

In a retrospective study, Alsalaheen et al. (2010) focused on the post-concussive vestibular disorders. It found that dizziness is the most frequent symptom and is reported in 23-81 percent of the cases. Management of these symptoms can be a challenge after a concussion. The interventions used in this study include: gaze stabilization exercises (individual fixes their eyes on a target while moving their head) while sitting and standing, standing balance activities on foam with eyes closed and walking with balance challenges (head turns while walking around obstacles and heel-toe walking).

In the Alsalaheen et al. study, the ABC Confidence Scale questionnaire was used as well as the Dizziness Handicap Inventory (DHI). The DHI is an instrument that is used to evaluate a person’s disability level as it relates to their dizziness. There are 25 items that relate to physical, functional and emotional areas. The study also used gait and balance performance measures to include the DGI and Timed Up and Go (patient stands up from a chair, walks three meters at their normal speed and returns to the chair). Computerized Dynamic Posturography was used as well, and patients performed the Sensory Organization Test. The conclusion of this study was that there was a significant treatment effect for both self-report and treatment measures after the vestibular rehabilitation therapy.

Conclusions
The VOR (the reflex that keeps eye movements stable while the head moves) connects the peripheral vestibular system with the central vestibular processing areas. It is imperative that we incorporate specific vestibular exercises for those patients who are at risk for falls, have impaired gait and/or have symptoms of dizziness. Vertigo and dizziness can be very debilitating conditions. Part of the evaluation process at Rainbow for patients that have sustained a TBI include a thorough assessment of their vestibular system when symptoms are present. This can be done through oculomotor testing, DGI, Modified Clinical Test of Sensory Interaction on Balance, TUG, sensory test on feet, and strength and ROM.

It is clear that incorporating vestibular therapy into the rehabilitation process of those who have sustained a brain injury can have excellent results in returning their function and reducing their risk for falls.

References


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Dix-Hallpike maneuver
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Epley maneuver
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