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Practice Guidelines: Addressing Vestibular and Visual Problems in the Neurologically Impaired Adult

Mary J. McGuire
Rehab Educators, LLC – USA, mjmotr@gmail.com

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Practice Guidelines: Addressing Vestibular and Visual Problems in the Neurologically Impaired Adult

Abstract

The visual and vestibular problems experienced by adults post brain injury (concussion, traumatic brain injury, cerebral vascular accident, tumor removal, etc.) must be evaluated and treated in conjunction with each other for best outcomes. The American Occupational Therapy Association's (AOTA) Practice Framework categorizes both the visual and vestibular sensory systems as client factors (body functions) that are a part of the scope of practice of occupational therapy (AOTA, 2020). AOTA's statement on vestibular impairment, vestibular rehabilitation, and occupational performance emphasizes the importance of occupational therapists addressing this critical client factor. The skills of entry-level and advanced-level occupational therapists are outlined in that document (AOTA, 2017). The objective of this article is to provide practical guidance to support advanced-level occupational therapists in more careful analysis of vestibulo-ocular skills that are needed for safe and efficient occupational performance. Literature and conceptual models from 1986 to 2021 from the fields of occupational therapy, physical therapy, ophthalmology, optometry, audiology, neurology, and otolaryngology that address the visual and vestibular problems experienced by adults with traumatic brain injury were reviewed and compared. Two models are presented to provide a framework to guide occupational therapy assessment and intervention of clients with neurological disorders who have vestibulo-ocular deficits that interfere with occupational performance.

Comments

The author declares that they have no competing financial, professional, or personal interest that might have influenced the performance or presentation of the work described in this manuscript.

Keywords

vestibular, visual-perceptual, traumatic brain injury, multisensory integration

Cover Page Footnote

I would like to extend my deep respect to Dr. Mary Warren for all the contributions she has made to our profession, not the least of which is the visual-perceptual hierarchy published in 1993. I offer this work, modifying that model, to support occupational therapists in integrating the vestibular system into the assessment and treatment of clients who have visual-perceptual deficits. I also want to acknowledge the hospitality of Dr. David Zee and the amazing scientists associated with his weekly Ocular Motor and Vestibular Lecture series hosted by Johns Hopkins University. I have enjoyed learning from the best, and I hope this work helps other occupational therapists to better integrate the complex visual and vestibular systems. There is more left out of this article than is in it. I hope this selection of information accurately reflects the work of the authors cited and leads readers to offer interventions that result in great outcomes for clients. "For now we see in a mirror dimly, but then face to face; now I know in part, but then I shall know fully just as I also have been fully known." -1 Corinthians 13:12

Erratum

4/18/22: Corrected spelling error in Figure 2 title; corrected one reference source error 4/22/22: Corrected additional reference source errors

Credentials Display

Mary Jo McGuire, MS, OTR/L, FAOTA

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It is critical for occupational therapists to recognize the importance of addressing vestibulo-ocular problems in clients who sustain traumatic brain injuries (TBI) and others with neurological disorders. The visual and vestibular problems that TBI clients experience and the impact of these impairments on activities of daily living are well-documented (Alghwiri et al., 2013; Barker et al., 2017; Cohen, Kane-Wineland, et al., 1995; Cohen, Miller, et al., 1995; Cohen, 2014; Cohen et al., 2003; Simpson-Jones & Hunt, 2019; Wright et al., 2017). This paper presents current clinical terminology and concepts, particularly about the visual and vestibular systems, and offers conceptual models to support an integrated approach to the evaluation and treatment of the vestibulo-ocular problems experienced by clients with neurological injuries. When occupational therapists address the visual and vestibular systems properly, intervention can help clients overcome vestibulo-ocular problems and return to meaningful occupations (vacuuming, loading the dishwasher, programing the microwave, picking up grandchildren, participating in exercise at the gym, gardening, driving, etc.). This article offers concepts and models consistent with the role of the advanced level therapist as defined by the American Occupational Therapy Association (AOTA) in a statement written in 2017 on the role of the occupational therapist in vestibular rehabilitation.

In 1993, Mary Warren authored a two-part article that presented a hierarchical model for evaluating and treating visual perceptual dysfunction in adult acquired brain injury. This well-accepted model provided a foundation for understanding the critical importance of screening acuity, peripheral and oculomotor skills prior to assessing visual attention, scanning, and higher-level perceptual skills. Neither of the articles, however, mentions the vestibular system. Warren's work highlights the importance of having a model to advance best practices and inspire and guide research. She wrote that her model was "only the first step" (Warren, 1993b, p. 64). At this point in the development of our professional role in assessing the cognitive-perceptual problems experienced by clients with acquired brain injury and other neurological disorders, the 1993 model needs to be updated to integrate information about the vestibular system and provide specificity regarding vestibulo-ocular skills to address in these populations.

Visual and vestibular problems must be carefully examined to develop effective intervention plans that target fundamental concerns in each system and the higher-level integrative problems caused by a lack of neural integration of stimuli from the sensory receptors. Researchers and authors outside of the field of occupational therapy use the following terms: sensorintegrative dysfunction (Franke et al., 2012), sensorimotor impairment (Liston et al., 2017), sensory integration (Freeman et al., 2018), sensory organization (Row et al., 2019), and multisensory integration (Bronstein, 2016; Miller et al., 2009). In the journal *Hearing Research*, Stein et al. (2009) define the term multisensory integration as: "a process by which information from different sensory systems is combined to influence perception, decisions, and overt behavior" (p. 4). This article uses the term multisensory integration to promote communication between occupational therapists and other disciplines to advance the evaluation and treatment of vestibulo-ocular function in adults with neurological disorders. A brief review of research and information related to the visual and vestibular systems is presented below before the presentation of the conceptual models.

Visual System

A 2007 retrospective study of the occurrence of oculomotor dysfunctions in acquired brain injury concluded that the majority of individuals with TBI (90%) or cerebral vascular accidents (86.7%) manifested an oculomotor dysfunction (Ciuffreda et al., 2007). Visual screenings for disorders vary in their scope and depth of analysis. In 2014, Radomski et al. provided guidance for a vision screening of service members with TBI. Their work considered 29 different tests and summarized the consensus of optometrists and occupational therapists (Radomski et al., 2014). This team recommended screening the following skills: self-reported symptoms and performance (including photosensitivity), far acuity, reading, accommodation, convergence, eye alignment and binocular vision, saccades, pursuits, and visual fields. In 2015, Barnett and Singman categorized vision concerns post TBI as afferent visual dysfunction (acuity, color, contrast deficits, visual field deficits, visual attention deficits, and visual midline shift), efferent visual defects (accommodation deficits, nystagmus, pursuits, saccades, strabismus, stereopsis, pupillary reaction), and higher-order deficits (sensitivity to glare, reading deficits, reaction time, memory impairment). In 2016, Berger et al. published a systematic review of interventions to address visual and visual-perceptual impairments in adults with TBI. Their literature analysis embraced Warren's 1993 categorization of basic visual skills as acuity, visual field, and oculomotor skills and added a general category of visual perception that they considered an aspect of cognition. Also in 2016, Roberts et al. (2016) developed a conceptual model for vision rehabilitation to facilitate interprofessional communication and implementation of best practice guidelines. Their work distinguishes visual function and visual impairments from functional vision and visual dysfunction. Their list of visual impairments includes accommodative deficits, vergence deficits, strabismus, pursuit/saccade deficits, diplopia, cranial nerve palsy, fixation deficits, visual field deficits, visual acuity deficits, and contrast sensitivity glare. They state that oculomotor dysfunction has been estimated to be as high as 90% in individuals with TBI (Roberts et al., 2016).

In 2018, in a review of visual problems associated with TBI, Armstrong described defects in primary vision (visual acuity; visual fields; and eye movements, including vergence, saccadic, and smooth pursuit movements) as well as more complex aspects of vision (visual perception, motion vision, and visual-spatial function). Armstrong emphasized the importance of assessing problems in saccades, pursuits, and convergence insufficiency since problems with these skills are frequent features of TBI. His work emphasizes that tests of eye movements that assess higher brain function and various diffuse brain pathways may be especially useful in identifying brain injury (Armstrong, 2018).

It should be noted that the past 28 years of scholarly work have added specificity in terminology and an increased awareness of how systems work together that must be applied to practice.

The Vestibular System

The field of occupational therapy was enlightened about the critical role of the vestibular system by the pioneering work of A. Jean Ayres. In the late 1960s and early 1970s, she applied concepts related to intersensory integration, convergent neurons, and the pervasive role of vestibular stimuli to her work with children (Ayres, 1969; Lane et al., 2019). Dr. Helen Cohen, AOTA's Eleanor Clarke Slagle lecturer of 2015, has researched, written, and lectured prolifically to advance occupational therapy's understanding of the vestibular system (Cohen et al., 1993; Cohen, Kane-Wineland, et al., 1995; Cohen & Keshner, 1989; Cohen, Miller, et al., 1995; Cohen, 2014; Cohen, 2015; Cohen & Kimball, 2008; Cohen et al., 2018).

The identification of vestibular problems often begins with a client's complaint of dizziness or sense of imbalance, a fall, the clinical observation of postural deficits while seated (inability to maintain a midline posture), deficits in dynamic balance or imbalances during gait, or complaints related to an intolerance of dynamic visual stimuli. Standardized subjective rating scales, such as the Dizziness Handicap Inventory (Jacobsen & Newman, 1990; Van Vugt et al., 2020), the Vestibular Activities and Participation Measure (Alghwiri et al., 2013), the Activities-Specific Balance Confidence Scale (Powell & Myers, 1995), and the Vestibular Disorders Activities of Daily Living Scale (Cohen & Kimball, 2000), can provide baseline information regarding the impact of vestibular impairments on the client's ability to function. The underlying reasons for these problems must then be determined, including whether there is a peripheral vestibular problem (described below) or if there is a central vestibular processing problem impairing function. Careful analysis of eye movement disorders, combined with a knowledge of neural circuitry, enables neurotologists (medical doctors who specialize in neurologically based ear disorders, including vertigo and balance problems) to diagnose where the lesion or disorder exists (Kheradmand et al., 2016).

For occupational therapists, a clear understanding of various types of vestibular disorders is important to refer clients to the proper specialists to obtain a proper diagnosis, as well as to design an effective plan of care. For instance, clients who complain about a brief period of dizziness when they lie down or only when moving into certain positions would benefit from seeing a vestibular specialist equipped with video Frenzel goggles or similar technology to rule out or treat benign paroxysmal positional vertigo (BPPV). If BPPV is not present, clients may benefit from a referral to a neurotologist for a more comprehensive evaluation. One client treated by this author, who was 4 years post-TBI, was experiencing imbalance deficits and demonstrated abnormal eye movements during a pursuit screening; her eyes could not smoothly cross the midline and would appear to "jump." That abnormal little jump, along with vestibular-related problems, resulted in a referral to a neurotologist who diagnosed post-traumatic labyrinthitis that was successfully treated by medical intervention. The neurotologist also recommended vestibulo-ocular exercises for the client; however, the client's memory was impaired, and she had difficulty recalling how to perform and adjust the exercises described by the doctor. The occupational therapist trained the client at home and designed forms for the client to properly monitor and grade her practice of these exercises. She was also diagnosed with a 30% hearing loss in her right ear that she had suffered from since the accident; she reported that this explained why she could not properly hear when her daughter was seated as a passenger in the car.

Cullen describes the vestibular system as "comprised of five sensory organs within the inner ear: the three semicircular canals and the two otoliths (the utricle and saccule)" (2019, p. 346). Disorder in these sensory organs can result in what is termed a peripheral vestibular disorder. There are different types of peripheral vestibular disorders. In a 2005 study, researchers found that about 50% of the patients with severe TBI experienced vertigo related to a BPPV (Motin et al., 2005, p. 693). Beyond peripheral vestibular disorders, it is common for clients with acquired brain injury to experience central vestibular disorders. Central vestibular disorders result from the brain not properly processing and integrating information from the vestibular system. It is critical to address BPPV when present and before designing a vestibular habituation or vestibular-ocular retraining program.

Information transmitted from the vestibular receptors is processed at various levels in the brain. Cullen states:

> Recent findings indicate that, in mammals, some multisensory and motor signals are combined at early stages of vestibular processing—a feature of this sensory system that has important implications for understanding the cortical representation of self-motion—whereas other integration does not take place until higher levels of processing. (2019, p. 351)

Visual-vestibular convergence predominantly occurs farther along the vestibular pathway in the vestibular cerebellum, thalamus, and cortex (Cullen, 2019). Cullen (2019) also describes "multisensory integration at higher stages of vestibular processing" in the article:

> The deep cerebellar nuclei and the vestibular nuclei send ascending projections to the ventral posterior lateral thalamus, which is also the main somatosensory nucleus of the thalamus. Neurons in this this thalamic nucleus are multimodal; they encode both vestibular signals and information provided by other inputs, including somatosensory, proprioceptive and/or visual sensory information and motor signals. Accordingly, and in contrast to the visual and auditory systems, no specific region of the cortex is specifically dedicated to vestibular processing. (p. 356)

Readers are referred to Cullen's article for an overview of vestibular encoding and what she refers to as extensive "multisensory integration" in the cortical vestibular network (2019, p. 358). Damage to the central nervous system along the vestibular pathways described above can result in central vestibular disorders. Dieterich states that "the most important structures for central vestibular forms of vertigo are the neuronal pathways for mediating the vestibulo-ocular reflex (VOR)" (2006, p. 560). In addition, Dieterich states:

> disorders of the VOR are not only characterized by ocular motor deficits, but also by disorders of perception due to impaired vestibulocortical projections of the VOR and by disorders of postural control due to impaired vestibulospinal projections of the VOR. (2006, p. 560)

For the purposes of this article, it is clear that vestibular input is integrated with sensory information from the other modalities at various levels in the central nervous system and plays a critical role in perception and action (AOTA, 2017; Cohen & Keshner, 1989; Cullen, 2019; Gurley et al., 2013; Rizzo et al., 2017; Schubert & Migliaccio, 2019; Stein, 2009).

Assessing the Vestibular System

Dr. Hamid Djalilian, the Director of Otology, Neurotology, and Skull Base Surgery at the University of California, Irvine, provides this clear instruction: "The function of the vestibular organ is to control balance and eye movements" (Djalilian, 2011). It follows, then, that the clinical assessment of balance and eye movements should provide a foundation for understanding the status of the vestibular system and for informing rehabilitation efforts post brain injury.

An assessment of the adult vestibular system that is commonly performed by neurologists, otolaryngologists, and audiologists is the administration of the videonystagmogram (VNG). The VNG is a series of tests that closely analyze the inner ear's functions and the vestibulo-ocular system. This test is not routinely done on clients with TBI; often, the screenings done by therapists can indicate the need for a VNG to identify the causes of the problems a client is experiencing.

There are many standardized balance tests available that can be used to look at imbalance, although most of them have been developed for the elderly and have been evaluated for their usefulness in predicting falls. Cohen and Kimball (2008) analyzed the effectiveness of these balance assessments (the Berg Balance Scale, the Timed Up and Go, and the Dynamic Gait Index) in identifying individuals with disequilibrium because of vestibular problems. Their work indicates that these tools had a moderate level of sensitivity and specificity; computerized dynamic posturography, particularly combined with an obstacle avoidance task, had the highest sensitivity for identifying clients with vestibular disorders (Cohen & Kimball, 2008).

Computerized posturography is one of the most respected assessments available for assessing balance. The Sensory Organization Test by NeuroCom is a form of posturography that requires complex hardware and software to assess a client's ability to maintain an upright posture in six different conditions

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(Chaudhry et al., 2004). The equipment needed for this assessment is costly; most clinicians do not have access to this computerized assessment. The Clinical Test of Sensory Interaction on Balance (CTSIB) (Shumway-Cook & Horak, 1986) was developed to offer a more reasonably priced clinical tool that could capture information similar to the Sensory Organization Test. These tests vary the sensory input a client receives by either permitting vision, altering vision, or occluding vision, while simultaneously controlling the base of support to require postural adjustments. The client's response to these various conditions provides data to determine which systems are effectively helping the brain maintain balance. Cohen and colleagues (1993) showed that the CTSIB is a useful screening tool for identifying adults with impairments in vestibular function from neurologically asymptomatic adults. An item in the original version of the test (a swinging lantern that provided challenging visual input) was later removed to create the modified CTSIB (mCTSIB). The mCTSIB is a standardized assessment tool available for clinicians to provide insight into the balance deficits caused by problems in multisensory integration post TBI (Cohen et al., 2019).

Integrating Assessment of Vestibular and Visual Functions

Careful assessment of the vestibulo-ocular functions of a client will inform the clinical reasoning necessary for the design and selection of effective interventions. Cohen et al. (2018) published a study that demonstrated the low sensitivity of many tests commonly used to identify vestibular disorders. Their work advises against using head shaking, un-instrumented head impulse tests (HT), and video head impulse tests (vHIT) to screen for vestibular disorders.

The Vestibular Ocular Motor Screening is a tool developed to assess clients with sports-related concussions. It challenges the client to perform various vestibulo-ocular tasks and then asks for a subjective rating of change related to common problems experienced if the systems are not working well (headache, dizziness, nausea, fogginess) (Mucha et al., 2014). Researchers examining vestibular and visual dysfunction following pediatric concussion report that vestibular and visual/oculomotor deficits are highly prevalent following concussion in children, and that abnormal saccades, balance, and symptoms with VOR testing correlated with prolonged recovery time from concussion (Master et al., 2016).

The vestibular and visual systems work together and must be carefully assessed to identify problems with the VOR, particularly when there are problems with gaze stabilization. Cohen and Keshner (1989) explain how observations of conjugate eye movements provide information on the integrity of the vestibular system.

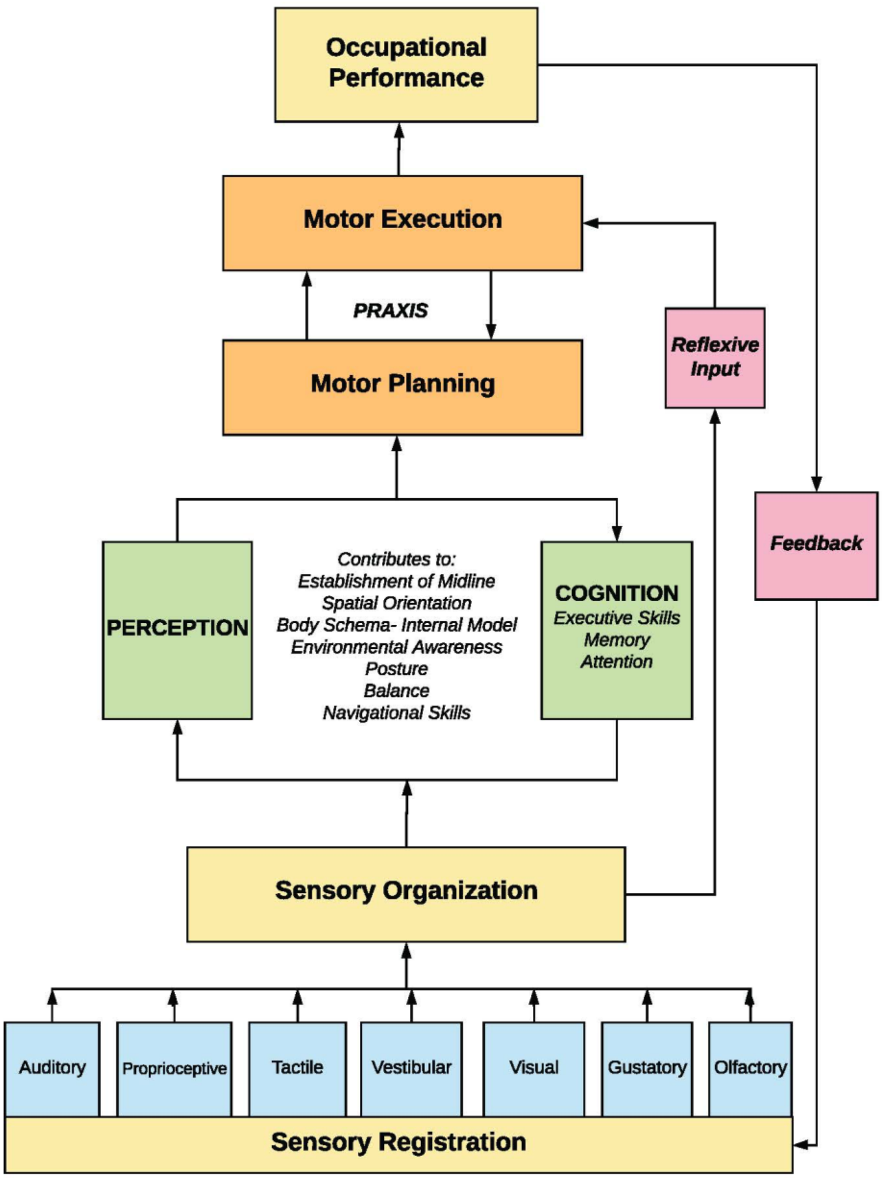
Gaze stabilization must be carefully analyzed, not only for the ability to maintain fixation in midline when the head is moved but also in terms of its function in different quadrants or when increased demands are put on the client in terms of cognitive load or postural challenges. A client may not have problems when asked, while seated in a quiet environment, to hold a fixation in midline and shake his or her head back and forth. The same client may have great difficulty maintaining fixation on a target (as when reading a sign) while driving. Clinicians must integrate the effects of cognitive load, assess the impact of dynamic visual stimuli, and consider the ability of the client to intentionally locate targets using saccadic movements into all quadrants in a variety of postural sets (Ettenhofer et al., 2018). The scholarly work from the areas of vision rehabilitation and vestibular rehabilitation are integrated into the two following models to guide clinicians and researchers in advancing their work in this area.

A Model of Multisensory Integration

Figure 1 presents a *Model of Multisensory Integration*. This macro model supports our understanding of the importance of multimodal integration necessary for sensorimotor adaptation (see

Figure 1). The term sensory organization represents the early complex neural circuitry that enables the brain to integrate sensory information from the various modalities (vision, vestibular, proprioceptive, etc.). With its critical input regarding gravitational forces, the vestibular system is recognized as having an essential role in supporting the brain's development of an internal model regarding the body's position in space (Carriot et al., 2015). It is also recognized as critical for developing the establishment of midline, spatial awareness, navigational skills, body schema/internal representation, and environmental awareness (Carriot et al., 2015; Cullen, 2019). Sensory organization and the convergent neurons and multiple layers of neural integration provide input that contributes to perceptual awareness; this perceptual awareness can be altered by cognitive input. Cognitive function can be generally categorized into skills related to attention, memory, and executive skills (Levy & Burns, 2005). The fact that the perception of sensory input can be altered by cognitive functions has important clinical implications that will be discussed later in the article.

Figure 1
A Model of Multisensory Integration



This multisensory integration model clearly separates the process of motor planning from that of motor control; praxis is placed in the center of these functions. Apraxia describes a complex set of disorders that can be traced back to sensory organizational dysfunction in many clients. The continuum of motor apraxia, ideomotor apraxia, and ideational apraxia all involve motor planning disorders that can be analyzed using this model of multisensory integration.

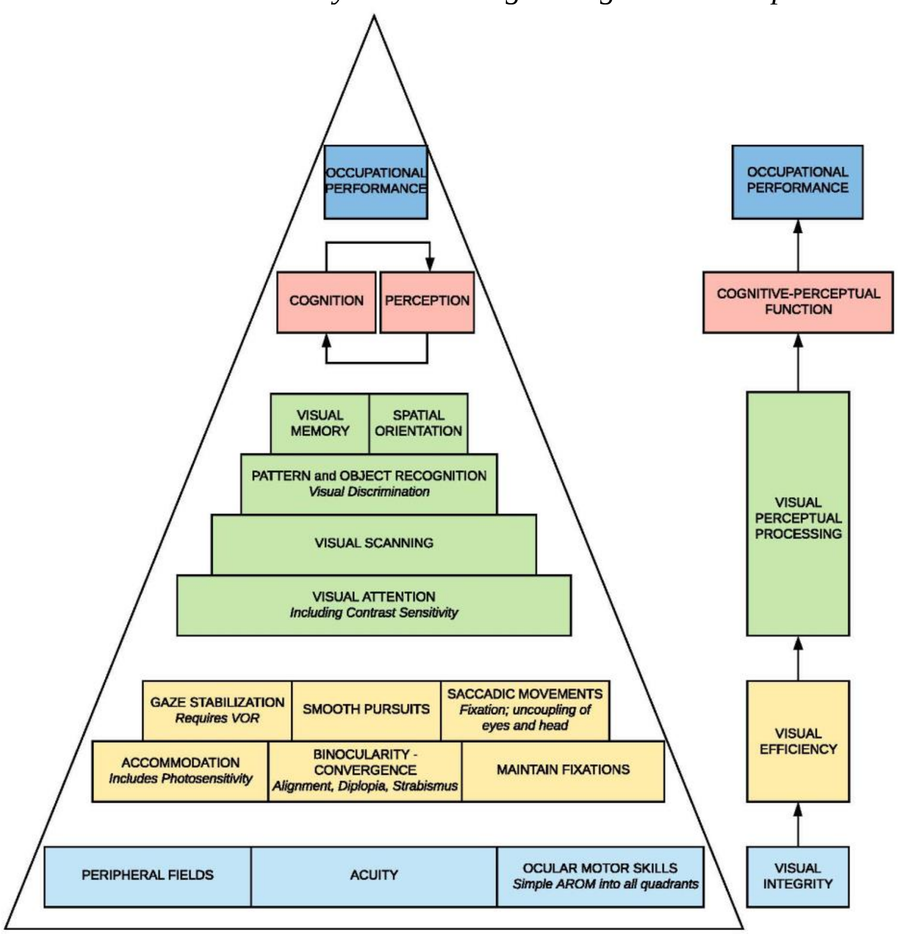
Researchers have recently focused on the importance of eye control and the impact of impairments in the timing of saccadic movements and on motor planning in neurorehabilitation (Rizzo et al., 2017). Understanding the importance of sensory registration and organization of vestibulo-ocular stimuli can impact the therapeutic principles used in rehabilitation of motor control. For instance, perhaps interventions addressing motor control of the upper extremity must be preceded or at least accompanied by a closer look at saccadic accuracies, gaze stabilization, and other vestibulo-ocular issues (Rizzo et al., 2017).

A Vestibulo-Ocular Hierarchy Model

Figure 2 models a hierarchy of vestibulo-ocular functions that contributes to cognitive-perceptual skills for occupational performance. Note that this hierarchy seeks to carefully analyze specific client factors of the visual and vestibular system; this information is embedded into the multisensory model presented above. Occupational performance continues to provide environmental and sensory feedback to the human being that must be perceived and understood.

Figure 2

Vestibulo-Ocular Hierarchy Contributing to Cognitive-Perceptual Skills for Occupational Performance



Visual Integrity: Acuity, Peripheral Fields, and Ocular-Motor Function

This model differentiates ocular-motor function from oculomotor skills. The more basic ocular-motor function refers to the client's ability to move each eye into all four quadrants.

Cranial nerve abnormalities are unlikely to occur in mild TBI unless there is a pre-existing abnormality (Dhaliwal et al., 2006). Moderate and severe TBI can result in cranial nerve palsies and optic neuropathies. Only 3%–11% of TBI clients have damage to cranial nerve III, 3%–13% have cranial nerve IV damage, and only 4%–6% have been shown to have cranial nerve VI damage (Ventura et al., 2014). Assessment protocols of acuity, peripheral fields, and ocular-motor function are well-documented in the literature (Gutman & Schonfeld, 2019; Scheiman, 2011; Zoltan, 2007), and readers are referred to those sources for instruction.

Visual Efficiency Skills: Binocularity, Convergence, Accommodation, Target Fixations, Saccadic Movements, Gaze Stabilization, and Smooth Pursuits

Scheiman, 2011, classifies accommodation, binocularity, convergence, fixation, saccades, and pursuits as "visual efficiency skills" (p. 57–58). The client's ability to achieve one clear image using the eyes together begins by noting the alignment of the eyes. Binocularity is the ability of the eyes to work together. When a client's eyes are not aligned, the brain can receive two different images; there is potential for blurriness, diplopia, convergence insufficiencies, or suppression of one image. Convergence is the ability of the two eyes to focus on a target; there is a high incidence of convergence insufficiency in the TBI population. Typically, clinicians look for a near point convergence of 5–10 centimeters from the nose (Ventura et al., 2014). The Brock String is a simple tool that can quickly assess binocularity and suppression. Clients who are distressed by convergence screening or show significant problems should be asked to complete the Brain Injury Vision Symptom Survey Questionnaire (BIVSS) and are referred to a functional optometrist for further evaluation (Laukkanen et al., 2017). Accommodation is assessed to determine the efficiency of the eyes in changing focus from near to far vision and back. Problems with accommodation can be seen when a person is walking and looking at a distance and then must look down quickly to assess the topography of the ground or floor (to see steps or understand markings on the ground). Accommodation skills are also used when a person is copying information from a blackboard or whiteboard or screen onto a written surface or looking down at a keyboard. It is also used when a person is driving and looking at the traffic in the distance but glances down to see the speedometer or the gas gauge and then returns to viewing traffic.

The next level of oculomotor skills addresses fixation skills. A client's ability to locate and maintain fixation on a target in each quadrant should be assessed before looking at saccadic movements. Peripheral field cuts, assessed as part of visual integrity, are considered. Clinical observations can often note a client's difficulty maintaining fixations in one quadrant or hemi-space, particularly when there are environmental distractions in another quadrant. This careful assessment helps therapists distinguish between a visual field cut and unilateral disregard.

A saccade is a rapid movement of the eye(s) used to fixate a target on the fovea(s) for central vision. There is a difference between reflexive saccades, such as those stimulated by movement in the peripheral field, and intentional saccades, such as those a person initiates following commands to focus on a specific target. The parietal eye field is the primary control center for reflexive saccades; the frontal eye field is the primary control center for intentional saccades. Clients with central vestibular problems often demonstrate normal reflexive saccadic movements but have difficulty initiating saccades when asked to focus on a specific target.

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Clinicians assess the accuracy and efficiency of intentional saccadic movements by asking a client to move his or her eyes between two targets under varying conditions. The clinician observes the client's ability to follow directions, demonstrate quick, accurate saccadic movements between targets, and separate eye movements from head movements. Saccadic movements are typically assessed using near vision (approx. 16" away from eyes) but should also be assessed using more distant vision.

- Head and eyes "coupled" – client permitted to move the head and eyes together
- Head and eyes "uncoupled" – eyes lead while the head stays fixed; then the head moves

The peripheral field programs saccadic movements; a neurotypical person can move from one target to another in one accurate saccadic movement. One indicator of vestibulo-ocular problems is hypometric saccadic movements. Another red flag is when clients spontaneously blink when moving their eyes between targets; this can happen with the head and eyes coupled or uncoupled. Neurotypical subjects can inhibit eye blinking when directed not to blink when moving the eyes or turning the head. Blinking decreases the optic flow. Clients with vestibulo-ocular problems have difficulty processing dynamic visual stimuli. Clients with vestibulo-ocular problems are often surprised at the inability to move between targets without blinking; they can become distressed, irritable, or embarrassed because it takes so much cognitive energy to inhibit blinking when the head is moving.

Therapists then assess gaze stabilization skills. The client is directed to fixate on a target and turn the head away from the target. One aspect of gaze stabilization problems is evident when a client will "let go" of the target as the head moves. Some clients with vestibulo-ocular problems will laugh (or cry) because they cannot follow such "simple" directions, and some express confusion. They seem to have difficulty understanding the relatively simple directions. Others report a pulling on their eyes, a headache, or a sense of instability or nausea; some demonstrate autonomic nervous system responses of yawning, burping, or hiccupping. The client's ability to understand and follow directions and any negative symptoms should be noted (confusion, nausea, headache, yawning, burping, or hiccups).

Researchers have documented that TBI clients demonstrate increased saccadic impairment under an increased cognitive load (Ettenhofer et al., 2018). This careful assessment of saccadic movements places an increased cognitive load on the client and can uncover problems with saccadic accuracies that are important for safe participation in higher-level functional skills, such as driving.

Rizzo et al. (2017) researched the saccadic movements of stroke clients compared to normal subjects. They identified that the clients with cerebral injury had not only hypometric saccades but also a greater number of anticipatory saccades. Of note, the stroke clients were unable to inhibit the saccadic movements until receiving the "go" signal. This disinhibition of saccadic movements is consistent with other disinhibition problems identified in clients with brain injury.

Schubert and Migliaccio (2019) published a review of research into the VOR and the implications for rehabilitation that supports what they term incremental VOR training that pushes the cognitive load one step further. The client begins with a visual fixation on a target and then moves the head in one direction while the eyes follow a red laser beam in the opposite direction (Schubert & Migliaccio, 2019). The red laser beam slowly challenges the client to increased distances of saccadic movements and pursuits. Their research on the effectiveness of incremental VOR training demonstrated improvements in the client's vestibular function.

Screening for smooth pursuits is a critical role of occupational therapists in evaluating the vestibulo-ocular skills of clients. This is typically done by having a client hold the head steady and follow an object, often in the shape of a large circle, X, or H pattern, moved by the clinician. Clinicians watch for abnormal movements like a jump or minor glitch in the eye movement, particularly when crossing midline. When abnormalities are found, clients need to be referred for further diagnosis. Wallace and Lifshitz (2016) emphasize the importance of assessing the interaction between the smooth pursuit system and the vestibulo-ocular reflex via the VOR cancellation test:

> The subject is asked to fixate on a moving target while the head is moved in the same direction. For example, the subject can extend out their arms, clasp their hands together, and extend their thumbs. The head and body rotate together back and forth while the subjects maintain their gaze on their thumbs. Findings should be consistent with results in the smooth pursuit test. An abnormal finding is observation of corrective saccades and/or provocation of symptoms. (p. 160)

The VOR cancellation test is an important step in assessing vestibulo-ocular function because a spike in negative symptoms when performing this test indicates a client is unable to inhibit the VOR. This is a common problem associated with motion sensitivity and is common in the brain-injured population. Wallace and Lifshitz (2016) explain:

> When the head and eyes are moving together to track a single object, the VOR must be suppressed in order to maintain focus on the target. Dysfunction in suppression of VOR is a contributing factor to motion sensitivity, a symptom associated with slower recovery from postconcussion syndrome (PCS) symptoms (p. 158).

Visual Processing Skills: *Visual Attention, Visual Scanning, Pattern and Object Recognition, Visual Memory, and Spatial Orientation*

These skills are addressed after visual integrity and visual efficiency skills have been evaluated. Many respected sources describe the tools and interventions needed to address these areas (Gutman & Schonfeld, 2019; Scheiman, 2011; Warren, 1993a; Warren, 1993b; Zoltan, 2007).

Clinical Implications

Warren's model for the evaluation and treatment of visual perceptual dysfunction in adult acquired brain injury established a paradigm shift; before its publication, it was unfortunately common for clinicians to assess cognitive-perceptual skills without a clear baseline of the client's acuity, peripheral fields, oculomotor skills, or visual attention and scanning skills. Today, it is common practice for clinicians to screen these areas. However, the work in vestibular rehabilitation and vision rehabilitation post brain injury has greatly improved practice since Warren's model was developed in 1993. The models proposed in this article maintain the hierarchy established by Warren and add terminology and concepts recommended by researchers to guide clinicians in more careful analysis of the vestibulo-ocular skills that are important for the rehabilitation of clients with brain injury.

Careful Assessment of Eye Movements

The careful assessment of eye movements should be an integral part of the occupational therapy evaluation of clients post brain injury; the eye is a window into the state of the vestibular system. Now it is known that clients with mild TBI typically do not commonly have deficits with ocular-motor problems associated with cranial nerve damage (Dhaliwal et al., 2006); instead, problems with binocularity, convergence, accommodation, separating eye movement from head movement, initiating intentional saccades, locating targets under a cognitive load, and gaze stabilization associated with vestibulo-ocular reflexes and vestibular impairment are critical areas to assess. Adding the VOR cancellation test to visual screening is a valuable step. Bronstein (2016) points out that "the examination of VOR suppression is clinically useful because only central, not peripheral lesions impair VOR suppression" (p. 57). Clients who cannot tolerate the rapid processing of visual information behind the target or who cannot maintain a fixation on the moving target during this assessment may benefit from appropriate multisensory integration intervention.

Gaze Stabilization and Posture

Vestibulo-ocular problems can be suspected as part of what causes the stereotypical rigid posture of the ambulatory TBI client; the head stays in midline, the eyes centered, and the whole body turns when changing direction. This rigid posture enables the client to avoid challenging the vestibulo-ocular reflex and the concomitant problems with gaze stabilization. This may contribute to neck pain and a loss of AROM in cervical rotation. Careful assessment of the ability to "uncouple" head and eye movements may indicate that intervention directed to this area should precede work involving "uncoupling" the head from the trunk. Clients may not be able to tolerate intervention or may not follow through with home exercises directed at disassociating the head from the trunk until vestibulo-ocular skills are healthy enough for the client to integrate those systems.

Saccadic Movements and Cognition

The *Occupational Therapy Practice Framework* (AOTA, 2020) and the description of occupational therapy evaluation published by the American Medical Association in the CPT Manual (2020, p. 739) both include cognition as a part of occupational therapy practice. Problems in attention, memory, and executive skills are associated with impaired saccadic function (Ventura et al., 2014). Analyzing if an increased cognitive load decreases the efficiency of saccadic accuracy is an important step in identifying the problems clients are experiencing. These, in turn, affect function.

Concepts of Multisensory Integration

Therapeutic intervention directed at vestibulo-ocular integration provides foundational skills needed for establishing midline and an internal model of body scheme, for the development of spatial orientation and navigational skills, and for posture and balance needed for dynamic standing balance and movement of the body in space. The multisensory model provides clinicians and clients with a tool to visualize and understand the problems being experienced. Clinicians should explore higher-level problems of motor planning and motor control from a bottoms-up approach to ensure that lower-level skills (related to sensory organization) are providing a foundation strong enough for exercises and therapeutic activities directed at motor control. Otherwise, efforts to develop motor planning and control may not be effective because of vestibulo-ocular problems. Addressing and resolving these more basic issues should precede intervention in the higher-level skills.

Vestibulo-ocular Problems and Anxiety

The vestibular system is highly integrated with arousal, autonomic functions, and emotional modulation. Problems with the integration of vestibular input can contribute to general anxiety, fear, and strong negative emotions (Franke et al., 2012). Clinical observations of a client's responses to challenges during the assessment of vestibulo-ocular skills should be carefully noted. A decrease in these negative symptoms through rehabilitative efforts can easily be monitored to help clients realize the progress they are making in terms of the integration of vestibular input. The real goal, of course, is for clients to be able to initiate and participate in all the meaningful activities of life. Facilitating vestibulo-ocular skills and multisensory integration supports this rehabilitation.

Persistent Postural-Perceptual Dizziness

In recent years, the term persistent postural-perceptual dizziness (PPPD) has been presented to describe the long-term problems experienced by some clients who have had vestibular problems. PPPD (often referred to as 3 PD) is described as a chronic functional vestibular disorder that may have different subtypes (Holle et al., 2015; Popkirov et al., 2018; Staab et al., 2017). Visually complex or dynamic visual stimuli can exacerbate the symptoms. According to Staab et al. (2017), although the pathophysiologic processes underlying PPPD are not fully known, "it may arise from functional changes in postural control mechanisms, multi-sensory information processing, or cortical integration of spatial orientation and threat assessment" (p. 191). Holle et al. (2015) state that PPPD is based on "multisensory maladjustment involving alterations of sensory response pattern including vestibular, visual and motion stimuli" (p. e0142468). Visual hypersensitivity, unsteadiness and imbalance, and avoidance of environments with dynamic visual stimuli are common problems with clients with 3PD.

Addressing Visual Vertigo

Visual vertigo, or visually induced dizziness, is often experienced by clients who depend on the visual system to compensate for vestibular problems. Clients complain of an inability to tolerate dynamic or over challenging visual environments. Riding as a passenger in the car, walking across lines on crosswalks in parking lots, coping with children's spinning and brightly colored toys, moving past strangers in a supermarket, and watching fast-paced sequences on television can induce dizziness. Clinicians need to recognize that this syndrome is indicative of vestibular problems. Bronstein (2016) discusses intervention for this syndrome, stating:

> Critically, specific measures should be introduced in the rehabilitation program in order to reduce the patient's hyperreactivity to visual motion. The aim is to promote desensitization and increase tolerance to visual stimuli and to visuovestibular conflict. The treatment approach is one of progressive difficulty both for the visual stimuli selected and for the more or less challenging postural setting adopted during the visual stimulation. (p. 64)

This disorder is not simply a visual problem. It is a vestibulo-ocular problem, and the intervention must incorporate therapeutic activities that address both the visual and vestibular systems. Daily life is filled with occupations that can be graded as therapeutic activities addressing the integration of these two systems. For instance, while sitting on a porch watching traffic, a client can be directed to turn his or her head to the right and locate a specific target (e.g., a red car) and follow the car (pursue the target) while turning his or her head to the left as the car moves (this can also be done while looking out the window of a facility). If close enough to traffic, clients can be asked to capture a number or letter on a license plate. In another example, clients can be asked to walk down the aisles of any big box store and instructed to turn the head to the right and read ANY label, then turn the head to the left and read ANY label. Occupational therapists can quickly analyze how to grade the activity according to the client's response. Adjustments could include: starting with the client in a stopped position and grading the speed of the gait, grading the cognitive load by applying rules on the location of a target (bottom shelf, or bottom shelf on right and top shelf on left), or a specific color of an item, or locating items that cost above a specified amount, etc. When adding rules, the client will be scanning and processing information. This is more difficult than capturing a specific word or fixating on "any" target. The visual and vestibular systems are always working together; grading the challenge, including assessing the cognitive load, and considering the impact of environmental factors (noise, other shoppers, crying children, etc.) is an essential part of the

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skilled services of occupational therapy. The therapeutic activities available are as varied as the occupations in life.

Critical Role of Patient Instruction

The perception of sensory input can be altered by cognitive functions. After a neurological injury, clients must learn how to respond to altered sensations; conflict between the visual and vestibular systems often triggers an alarm in the human system. Therapy provides an opportunity for clients to learn to "listen" to the altered input, interpret it correctly, and develop adaptive responses. Clear instruction on the importance of multisensory integration and how the vestibular and visual systems work together can provide some clients with the strength to tolerate the altered sensations they are experiencing. Cognitive input alters the human being's ability to tolerate sensory input that otherwise could be interpreted as dangerous and elicit a flight response. For instance, cognitive override of distressing perceptual input is experienced when an individual visits amusement parks and chooses to ride and enjoy death-defying roller coasters. Cognitively, in this recreational model, a person believes he is safe despite visual and vestibular information relaying information that is contrary to that. Similarly, in rehabilitation, clinicians help clients habituate to visual and vestibular information that the brain interprets as unsafe.

The aVOR app, developed at the University of Sydney in the School of Psychology, is a free educational tool that can be downloaded onto Apple iPhones and iPads (Falls & LaBlanc, 2018). It is an excellent tool to help clients understand the basics of the vestibular system, where the receptors are in the inner ear, and the relationship of the semicircular canals to head and eye movement. Instruction regarding the vestibulo-ocular system, and the nervous system's difficulty processing conflicting or altered visual and vestibular stimuli, can alter the client's perception and relieve stress.

Frontal Eye Fields and Executive Function

Clients with damage to the frontal lobes are known to have difficulties with executive function. Scholars from different fields have various lists of what comprises executive skills. The work of Baum et al. (2008) targeted four key skills in evaluating executive function: initiation, organization, judgment, and task completion. An important construct commonly listed as an executive skill is initiation of action. The frontal eye field is involved in the "preparation and triggering of all intentional saccades" (Pierrot-Deseilligny et al., 2004, p. 18). Uncoupling eye movements from head movements can be challenging to clients post brain injury; the inability to follow such a "simple" directive reveals frontal lobe problems and reflects executive dysfunction that may be seen in many areas of occupational performance. Anti-saccades are assessed by asking a client to look away from a stimulus; this task is an executive skill that requires the inhibition of reflexive saccades and the intentional generation of a saccade processed through the_frontal eye field (Ventura et al., 2014, p. 1006). Could the simple exercises and activities to restore vestibulo-ocular function be a beginning for developing executive skills? Could the rehabilitation directed to restore vestibulo-ocular function support the client's effort to regain the ability to initiate action in other occupations that a client has problems initiating? Vision guides much of our actions. Research is needed to identify the impact of vestibulo-ocular rehabilitation that rely on frontal eye fields on the initiation of other occupations.

Conclusion

Survivors of TBI need a careful analysis of vestibulo-ocular skills that impair their occupational performance. AOTA acknowledges the role of advanced-level therapists in assessing saccades, pursuit, optokinetic nystagmus, vergence, visual-vestibulo-ocular reflex interaction, and evaluation of spontaneous nystagmus (2017). It also acknowledges the role of advanced-level therapists in designing exercises to promote nervous system habituation, gaze stabilization, and balance training. This article offers two conceptual models to support clinicians and researchers in a more careful analysis of vestibulo-ocular skills and their impact on perception, cognition, and occupation. The multisensory integration model incorporates concepts from many models and provides clinicians with a clear conceptual model to help clients understand why vestibulo-ocular problems are causing occupational disorders. The vestibulo-ocular hierarchy takes Warren's accepted model for the development of visual-perceptual skills and integrates concepts and terminology from vestibular and visual rehabilitation literature. The models presented in this article provide clarity for instruction, practice, and research in this area.

References

Alghwiri, A., Alghadir, A., & Whitney, S. L. (2013). The vestibular activities and participation measure and vestibular disorders. *Journal of Vestibular Research: Equilibrium & Orientation*, *23*(6), 305–312. https://doi.org/10.3233/VES-130474

American Medical Association. (2020). *CPT professional 2020* (Revised ed.).

American Occupational Therapy Association. (2017). Vestibular impairment, vestibular rehabilitation, and occupational performance. *American Journal of Occupational Therapy*, *71* (Suppl. 2), 7112410055. https://doi.org/10.5014/ajot.2017.716S09

American Occupational Therapy Association. (2020). Occupational therapy practice framework: Domain and process (4th ed.). *American Journal of Occupational Therapy*, *74* (Suppl. 2), 7412410010. https://doi.org/10.5014/ajot.2020.74S2001

Armstrong, R. A. (2018). Visual problems associated with traumatic brain injury. *Clinical & Experimental Optometry*, *101*, 716–726. https://doi.org/10.1111/cxo.12670

Ayres, A. (1969). Deficits in sensory integration in educationally handicapped children. *Journal of Learning Disabilities*, *2*(3), 160–168. https://doi.org/10.1177/002221946900200307

Barker, F., Cocherham, G., Goodrich, G., Hartwick, A., Kardon, R., Mick, A. B., & Swanson, M. (2017). Brain injury impact on the eye and vision. *Optometry & Vision Science*, *94*(1), 4–6. https://doi.org/10.1097/OPX.0000000000001001

Barnett, B. P., & Singman, E. L. (2015). Vision concerns after mild traumatic brain injury. *Current Treatment Options in Neurology*, *17*(2), 329. https://doi.org/10.1007/s11940-014-0329-y

Baum, C. M., Connor, L. T., Morrison, T., Hahn, M., Dromerick, A. W., & Edwards, D. F. (2008). Reliability, validity, and clinical utility of the Executive Function Performance Test: A measure of executive function in a sample of people with stroke. *American Journal of Occupational Therapy*, *62*, 446–455. https://doi.org/10.5014/ajot.62.4.446

Berger, S., Kaldenberg, J., Selmane, R., & Carlo, S. (2016). Effectiveness of interventions to address visual and visual-perceptual impairments to improve occupational performance in adults with traumatic brain injury: A systematic review. *American Journal of Occupational Therapy*, *70*(3), 1–7. https://doi.org/10.5014/ajot.2016.020875

Bronstein, A. M. (2016). Multisensory integration in balance control. In J. M. Furman & T. Lempert (Eds.), *Handbook of clinical neurology* (3rd ed., pp. 57–66). Elsevier.

Carriot, J., Jamali, M., & Cullen, K. E. (2015). Rapid adaptation of multisensory integration in vestibular pathways. *Frontiers in Systems Neuroscience*, *9*. https://doi.org/10.3389/fnsys.2015.00059

Chaudhry, H., Findley, T., Quigley, K. S., Bukiet, B., Ji, Z., Sims, T., & Many, M. (2004). Measures of postural stability. *Journal of Rehabilitation Research & Development*, *41*, 713–720. Retrieved from https://www.rehab.research.va.gov/jour/04/41/5/pdf/quigley.pdf

Ciuffreda, K. J., Kapoor, N., Rutner, D., Suchoff, I. B., Han, M. E., & Craig, S. (2007). Occurrence of oculomotor dysfunctions in acquired brain injury: A retrospective analysis. *Optometry*, *78*, 155–161. https://doi.org/10.1016/j.optm.2006.11.011

Cohen, H., Blatchly, C. A., & Gombash, L. L. (1993). A study of the clinical test of sensory interaction and balance. *Physical Therapy*, *73*(6), 346–351. https://doi.org/10.1093/ptj/73.6.346

Cohen, H., Kane-Wineland, M., Miller, L. V., & Hatfield, C. L. (1995). Occupation and visual/vestibular interaction in vestibular rehabilitation. *Otolaryngology-Head and Neck Surgery: Official Journal of American Academy of Otolaryngology-Head and Neck Surgery*, *112*(4), 526–532. https://doi.org/10.1177/019459989511200404

Cohen, H., & Keshner, E. A. (1989). Current concepts of the vestibular system reviewed: 2. Visual/vestibular interaction and spatial orientation. *American Journal of Occupational Therapy*, *43*(5), 331–338. https://doi.org/10.5014/ajot.43.5.331

Cohen, H., Miller, L. V., Kane-Wineland, M., & Hatfield, C. L. (1995). Vestibular rehabilitation with graded occupations. *The American Journal of Occupational Therapy*, *49*(4), 362–367. https://doi.org/10.5014/ajot.49.4.362

Cohen, H. S. (2014). Use of the vestibular disorders activities of daily living scale to describe functional limitations in patients with vestibular disorders. *Journal of Vestibular Research: Equilibrium & Orientation*, *24*(1), 33–38. https://doi.org/10.3233/VES-130475

Cohen, H. S. (2015). Eleanor Clarke Slagle Lecture: A career in inquiry. *American Journal of Occupational Therapy*, *69*(6), 1–2. https://doi.org/10.5014/ajot.2015.696001

Cohen, H. S., & Kimball, K. T. (2000). Development of the vestibular disorders activities of daily living scale. *Archives of Otolaryngology- Head and Neck Surgery*, *126*, 881–887. https://doi.org/10.1001/archotol.126.7.881

Cohen, H. S., & Kimball, K. T. (2008). Usefulness of some current balance test for identifying individuals with disequilibrium due to vestibular impairments. *Journal of Vestibular Research*, *18*(5-6), 295–303. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2819299/

Cohen, H. S., Mulavara, A. P., Stitz, J., Sangi-Haghpeykar, H., Williams, S. P., Peters, B. T., & Bloomberg, J. (2019). Screening for vestibular disorders using the modified Clinical Test of Sensory Interaction and Balance and Tandem Walking with eyes closed. *Otology and Neurotology*, 40(5), 658–665. https://doi.org/10.1097/MAO.0000000000002173

Cohen, H. S., Stitz, J., Sangi-Haghpeykar, H., Williams, S. P., Mulavera, A. P., Peters, B. T., & Bloomberg, J. J. (2018). Utility of quick oculomotor tests for screening the vestibular system in the subacute and chronic populations. *Acta Oto-Laryngologica*, *138*, 382–386. https://doi.org/10.1080/00016489.2017.1398838

Cohen, H. S., Wells, J., Kimball, K. T., & Owsley, C. (2003). Driving disability and dizziness. *Journal of Safety Research*, *34*(4), 361–369. https://doi.org/10.1016/j.jsr2003.09.009

Cullen, K. E. (2019). Vestibular processing during natural self-motion: implications for perception and action. *Nature Reviews Neuroscience*, *20*, 346–363. https://doi.org/10.1038/s41583-019-0153-1

Dhaliwal, A., West, A. L., Trobe, J. D., & Musch, D. C. (2006). Third, fourth, and sixth cranial nerve palsies following closed head injury. *Journal of Neuroophthalmology*, *26*, 4–10.

Dieterich, M. (2006). Central vestibular disorders. *Journal of Neurology*, *254*, 559–568. https://doi.org/1007/s00415-006-0340-7

Djalilian, H. (2011, September 8). *Vestibular (Balance Organ) Anatomy* [Video]. Youtube. https://www.youtube.com/watch?v=UTqoqO2XtMQ&feature=youtu.be&ab_channel=earsurgery

Ettenhofer, M. L., Hershaw, J. N., Engle, J. R., & Hungerford, L. D. (2018). Saccadic impairment in chronic traumatic brain injury: Examining the influence of cognitive load and injury severity. *Brain Injury*, *32*, 1740–1748. https://doi.org/10.1080/02699052.2018.1511067

Falls, C., & LeBlanc, E. (2018). aVOR: We walk you through an educational tool with the power to help you understand the vestibulo-ocular reflex. *Canadian Audiologist*, *8*. https://doi.org/https://canadianaudiologist.ca/issue/volume-5-issue-5-2018/avor-feature-1/

Franke, L. M., Walker, W. C., Cifu, D. X., Ochs, A. L., & Lew, H. L. (2012). Sensorintegrative dysfunction underlying vestibular disorders after traumatic brain injury: A review. *Journal of Rehabilitation Research and Development*, *49*(7), 985–994. https://pubmed.ncbi.nlm.nih.gov/23341274/

Freeman, D. L., Geetanjali, G., Horak, F. B., Blackinton, M. T., Besch, M., & King, L. (2018). The instrumented test of sensory integration for balance: A validation study. *Journal of Geriatric Physical Therapy*, *41*(2), 77–84. https://doi.org/10.1519/JPT.0000000000000110

Gurley, J. M., Hujsak, B. D., & Kelly, J. L. (2013). Vestibular rehabilitation following mild traumatic brain injury. *NeuroRehabilitation*, *32*(3), 519–528. https://doi.org/10.3233/nre-130874

Gutman, S. A., & Schonfeld, A. B. (2019). *Screening adult neurologic populations* (3rd revised ed.). AOTA Press.

Holle, D., Schulte-Steinberg, B., Wurthmann, S., Naegel, S., Ayzenberg, I., Diener, H. C., Katsarava, Z., & Obermann, M. (2015). Persistent postural-perceptual dizziness: A matter of higher, central dysfunction? *PloS One*, *10*(11), e0142468. https://doi.org/doi.org/10.1371/journal.pone.0142468

Jacobsen, G. P., & Newman, C. W. (1990). The development of the dizziness handicap inventory. *Archives of Otolaryngology--Head & Neck Surgery*, *116*, 424–427. https://doi.org/10.1001/archotol.1990.01870040046011

Kheradmand, A., Colpak, A. I., & Zee, D. S. (2016). Eye movements in vestibular disorders. In J. M. Furman & T. Lempert (Eds.), *Handbook of clinical neurology -neurotology* (3rd ed., pp. 103–117). Elsevier. https://doi.org/10.1016/B978-0-444-63437-5.00008-X

Lane, S. J., Mailloux, Z., Schoen, S., Bundy, A., May-Benson, T. A., Parham, L. D., Smith Roley, S., & Schaaf, R. C. (2019). Neural foundations of Ayres Sensory Integration®. *Brain Sciences*, *9*(7), 153. https://doi.org/10.3390/brainsci9070153

Laukkanen, H., Scheiman, M., & Hayes, J. R. (2017). Brain injury vision symptom survey (BIVSS) questionnaire. *Optometry and Vision Science*, *94*(1), 43–50. https://doi.org/10.1097/OPX.0000000000000940

Levy, L. L., & Burns, T. (2005). Cognitive disabilities reconsidered. In N. Katz & J. Toglia (Eds.), *Cognition and occupation across the life span* (2nd ed., pp. 347–388). American Occupational Therapy Association.

Liston, D. B., Wong, L. R., & Stone, L. S. (2017). Oculometric assessment of sensorimotor impairment associated with TBI. *Optometry and Vision Science*, *94*(1), 51–59. https://doi.org/10.1097/opx.0000000000000918

Master, C., Grady, M., Lockyer, J., Storey, E., Podolak, O., & Wiebe, D. (2016). Vestibular and visual dysfunction following pediatric concussion. *Journal of Neurotrauma*, *33*(13), A–98.

Miller, L., Nielsen, D. M., Schoen, S. A., & Brett-Green, B. A. (2009). Perspectives on sensory processing disorder: A call for translational research. *Frontiers in Integrative Neuroscience*, *3*. https://doi.org/10.3389/neuro.07.022.2009

Motin, M., Keren, O., Groswasser, Z., & Gordon, C. R. (2005). Benign paroxysmal positional vertigo as the cause of dizziness in patients after severe traumatic brain injury: Diagnosis and treatment. *Brain Injury*, *19*(9), 693–697. https://doi.org/10.1080/02699050400013600.

Mucha, A., Collins, M. W., Elbin, R. J., Furman, J. M., Troutman-Enseki, C., DeWolf, R. M., Marchetti, G., & Kontos, A. P. (2014). A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions. *The American Journal of Sports Medicine*, *42*, 2479–2486. https://doi.org/10.1177/0363546514543775

Pierrot-Deseilligny, C., Mileages, D., & Muri, R. M. (2004). Eye movement control by the cerebral cortex. *Current Opinion in Neurology*, *17*, 17–25. https://doi.org/10.1097/00019052-200402000-00005

Popkirov, S., Staab, J. P., & Stone, J. (2018). Persistent postural-perceptual dizziness (PPPD): A common, characteristic and treatable cause of chronic dizziness. *Practical neurology*, *18*(1), 5–13. https://doi.org/10.1136/practneurol-2017-001809

Powell, L. E., & Myers, A. M. (1995). The activities-specific balance confidence (ABC) Scale. *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *50*, 28–34. https://doi.org/10.1093/gerona/50A.1.M28

Radomski, M., Finkelstein, M., Llanos, I., Scheman, M., & Wagener, S. (2014). Composition of a vision screen for servicemembers with traumatic brain injury: Consensus using a modified nominal group technique. *The American Journal of Occupational Therapy*, *68*(4), 422–429. https://doi.org/10.5014/ajot.2014.011445

Rizzo, J.-R., Hudson, T., Abdou, A., Lui, Y. W., Rucker, J. C., Raghavan, P., & Landy, M. S. (2017). Disrupted saccade control in chronic cerebral injury: Upper motor neuron-like disinhibition in the ocular motor system. *Frontiers in Neurology*, *8*. https://doi.org/10.3389/fneur.2017.00012

Roberts, P. S., Rizzo, J. R., Hreha, K., Wertheimer, J., Kaldenberg, J., Hironaka, D., Riggs, R., & Colenbrander, A. (2016). A conceptual model for vision rehabilitation. *Journal of Rehabilitation Research and Development*, *53*, 593–704. https://doi.org/10.1682/JRRD.2015.06.0113

Row, J., Chan, L., Damiano, D., Shenouda, C., Collins, J., & Zampieri, C. (2019). Balance assessment in traumatic brain injury: A comparison of the sensory organization and limits of stability tests. *Journal of Neurotrauma*, *36*(16), 2435–2442. https://doi.org/10.1089/neu.2018.5755

Scheiman, M. (2011). *Understanding and managing vision deficits: A guide for occupational therapists* (3rd ed.). SLACK.

Schubert, M. C., & Migliaccio, A. A. (2019). New advances regarding adaptation of the vestibulo-ocular reflex. *Journal of Neurophysiology*, *122*, 644–648. https://doi.org/10.1152/jn.00729.2018

Shumway-Cook, A., & Horak, F. B. (1986). Assessing the influence of sensory interaction of balance. Suggestion from the field. *Physical Therapy*, *66*, 1548–1550. https://doi.org/10.1093/ptj/66.10.1548

Simpson-Jones, M. E., & Hunt, A. W. (2019). Vision rehabilitation interventions following mild traumatic brain injury: a scoping review. *Disability & Rehabilitation*, *41*(18), 2206–2222. https://doi.org/10.1080/09638288.2018.1460407

Staab, J. P., Eckhardt-Henn, A., Arata, H., Jacob, R., Strupp, M., Brandt, T., & Bronstein, A. (2017). Diagnostic criteria for persistent postural-perceptual dizziness (PPPD): Consensus document of the committee for the classification of vestibular disorders of the Bárány Society. *Journal of Vestibular Research: Equilibrium & Orientation*, *27*(4), 191–208. https://doi.org/10.3233/VES-170622

Stein, B. E., Stanford, T. R., & Rowland, B. A. (2009). The neural basis of multisensory integration in the midbrain: its organization and maturation. *Hearing research*, *258*(1-2), 4–15. https://doi.org/10.1016/j.heares.2009.03.012

Van Vugt, V. A., de Vet, H. C., van der Wouden, J. C., Van Weert, H. C., van der Horst, H. E., & Maarsingh, O. R. (2020). The 25-item dizziness handicap inventory was shortened for use in general practice by 60 percent. *Journal of Clinical Epidemiology*, *126*, 56–64. https://doi.org/10.1016/j.jclinepi.2020.06.021

Ventura, R. E., Balcer, L. J., & Galetta, S. L. (2014). The neuro-ophthalmology of head trauma. *Lancet Neurology*, *13*(10), 1006–1016. https://doi.org/10.1016/S1474-4422(14)70111-5

Wallace, B., & Lifshitz, J. (2016). Traumatic brain injury and vestibular-ocular function: Current challenges and future prospects. *Eye and Brain*, *8*, 153–164. https://doi.org/10.2147/EB.S82670

Warren, M. (1993a). A hierarchical model for evaluation and treatment of visual perceptual dysfunction in adult acquired brain injury, Part 1. *The American Journal of Occupational Therapy*, *47*(1), 42–54. https://doi.org/10.5014/ajot.47.1.42

Warren, M. (1993b). A hierarchical model for evaluation and treatment of visual perceptual dysfunction in adult acquired brain injury, Part 2. *The American Journal of Occupational Therapy*, *47*(1), 55–66. https://doi.org/10.5014/ajot.47.1.55

Wright, W. G., Tierney, R. T., & McDevitt, J. (2017). Visual-vestibular processing deficits in mild traumatic brain injury. *Journal of Vestibular Research: Equilibrium & Orientation*, *27*(1), 27–37. https://doi.org/10.3233/VES-170607

Zoltan, B. (2007). *Vision, perception, and cognition: A manual for the evaluation and treatment of the adult with acquired brain injury* (4th ed.). SLACK Incorporated.

***Mary Jo McGuire, MS, OTR/L, FAOTA**, has practiced occupational therapy for over 40 years, and admits to being fascinated by cognitive-perceptual issues throughout her career. She was a clinical supervisor and then clinical education specialist at the Rehabilitation Institute of Chicago (now the Shirley Ryan Ability Lab). She enjoyed 8.5 years as an academician, owned a continuing education company where she connected with experts in vestibular rehabilitation and cognitive and visual rehabilitation, and started a private practice where effective outcomes in her work with TBI clients inspired her to write this article to promote best practices in addressing vestibulo-ocular issues.*