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## Special Issue on Neuro-optometry

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# guest editor's message

Vision problems following traumatic brain injury (TBI) occur in 40% to 80% of these individuals. Examples of symptoms reported include blur, diplopia, slowed reading, eyestrain, photosensitivity, dry eye, visual field loss and restriction, and increased sensitivity to visual motion. Any of these vision problems can become a significant obstacle to the overall rehabilitation regimen. Therefore, the diagnosis and treatment of these conditions have become an increasingly important component to be addressed in the inter-disciplinary rehabilitation regimen.

I was both pleased and proud when I was invited to be the Guest Editor of this special issue of Brain Injury Professional on neuro-optometry. My goal for this special issue is to present recent contributions that optometry has made in the diagnosis and treatment of vision conditions related to TBI. Treatment options may include prescribing lenses, fusional prisms, field-expanding lenses, yoked prisms, vision rehabilitative therapy, as well as ocular pharmaceuticals.

To achieve this goal, I recruited several optometric leaders in the field of vision and brain injury to contribute articles. Topics include the rehabilitation of vergence and accommodative disorders in TBI, reading-related oculomotor deficits in TBI, diagnosis of visual inattention in acquired brain injury (ABI), management of visual field defects with and without inattention in ABI, the role of optometry in managing vestibular disorders, and case series exemplifying vision rehabilitation in ABI. With the exception of the case series, these articles present scientific background, followed by clinical pearls, regarding the diagnosis and treatment of the more common vision problems consequent to brain injury. This issue will offer the reader an appreciation of the benefits of optometric intervention in individuals with TBI, in terms of their vision rehabilitation and quality of life.

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# glossary of ophthalmic terms used in this issue

accommodation:
: the ability to change focus and maintain a clear image of an object (when looking from far to near and vice versa), using the eye's crystalline lens-based mechanism.

accommodative amplitude:
: the closest point of clear vision, typically performed monocularly.

anisometropia:
: asymmetric refractive errors between the eyes.

astigmatism:
: unequal refractive error in orthogonal meridians of the eye; when rays of light from infinity come to a focus at different distances relative to the retina, with accommodation minimally stimulated.

binocular:
: viewing with two eyes open at the same time.

convergence insufficiency:
: the vision diagnosis presenting with exophoria greater at near than far, with a receded near point of convergence and reduced relative fusional convergence at near.

diopter:
: the unit of lens power= 1/m.

diplopia:
: double vision.

esophoria:
: the lines of sight intersect in front of the plane of regard when fusion is disrupted.

exophoria:
: the lines of sight intersect beyond the plane of regard when fusion is disrupted.

fixation:
: ocular alignment with the image of the fixated target falling on the fovea; may be performed one eye at a time (i.e., monocularly) or with both eyes at the same time (i.e., binocularly).

fusion:
: single, cortically-integrated vision under binocular viewing conditions.

hemianopia:
: hemi-field visual field defect, which may be unilateral or bilateral (i.e., homonymous or bitemporal).

heterophoria:
: the position of the eyes when fusion is disrupted.

heterotropia (ie., strabismus):
: the position of the eyes when fusion is not disrupted (i.e., under normal binocular viewing conditions).

hyperopia:
: far-sightedness; when rays of light from infinity come to a focus behind the eye, with accommodation minimally stimulated.

lag of accommodation:
: the difference between the plane of the accommodative response and the actual plane of the near vision target being viewed.

monocular:
: viewing with one eye open at a time.

morphopsia:
: visual distortions

myopia:
: near-sightedness; when rays of light from infinity come to a focus in front of the eye, with accommodation minimally stimulated.

near point of convergence:
: the closest point of binocular, fused, single vision. Four parameters are recorded: the first is the distance at which one is no longer able to maintain fusion; the second is the distance at which one regains fusion; the third is whether or not one reports diplopia; and the fourth is which eye deviated when fusion is finally disrupted. Each parameter is separated by a backwards slash.

nystagmus:
: rapid involuntary oscillation or movement of the eyes, the presence or absence of which may be diagnostic of neurological and vision disorders.

orthophoria:
: the lines of sight intersect precisely at the plane of regard when fusion is disrupted.

presbyopia:
: normal age-related, physiological loss of accommodation.

prism diopter:
: the unit of prism power=cm/m

pursuit:
: slow, continuous, and conjugate eye movement used when the eyes follow an object as it is moved slowly and smoothly.

relative accommodative range:
: the range over which the accommodative system can be stimulated by the addition of plus (i.e., negative relative accommodation) and minus (i.e., positive relative accommodation) lenses binocularly and still maintain clear, single vision at near (40 cm).

relative fusional range:
: the range over which the vergence system can be stimulated by the addition of prisms binocularly and still maintain single, binocular vision at both distance (6 m) and near (40 cm). Three parameters are recorded: the first is the amount of prism at which one reports blurred vision; the second is the amount of prism at which one reports diplopia; and, the third is the amount of prism at which one regains fusion. Each parameter is separated by backwards slash.

saccade:
: rapid, step-like conjugate eye movement that redirects the line of sight from one position to another.

stereopsis:
: relative depth perception

strabismus (i.e., heterotropia):
: the position of the eyes when fusion is not disrupted (i.e., under normal binocular viewing conditions).

vergence:
: the disjunctive movement of the eyes to track targets moving in depth.

versional eye movements:
: the conjunctive movement (including fixation, pursuit, and saccade) of the eyes to follow targets moving laterally, vertically, or obliquely in one plane, with no change in depth.

# THE ROLE OF OPTOMETRY IN THE MANAGEMENT OF VESTIBULAR DISORDERS

by Allen H. Cohen, O.D., F.A.A.O., F.C.O.V.D.

## INTRODUCTION

Dizziness, vertigo, and gait disturbance are very common in individuals with traumatic brain injury (TBI). The impact of visual sensory motor vision function on vestibular function and associated rehabilitation become apparent and suggests the benefit of integrating vision and vestibular therapies to fully restore balance function. This article will discuss, in a clinically relevant format, the importance of including optometry as a member of the management team in dealing with vestibular dysfunction.

## OVERVIEW OF THE NEUROPHYSIOLOGY OF BALANCE

While a detailed discussion of vestibular neuroanatomy and associated areas of neurophysiology is beyond the scope of this article, a basic summary is helpful in understanding the role of vision with respect to balance. This system can be analyzed using the concept of an input/output model, which in human beings is referred to as the afferent-efferent model (Hain and Hillman, 1994). In humans, the balance has three contributing afferent systems: vestibular, visual, and somatosensory. The efferent system for balance consists of multiple neurological pathways. In order to maintain balance during various static and dynamic situations, all of these pathways must ultimately play a role in coordinating motor responses of the limbs, trunk, and eyes.

## NEUROPHYSIOLOGY OF THE VISUAL SYSTEM

Similar to the vestibular system, the visual system has both peripheral and central components. The peripheral component, which is comprised of the eye itself, the extraocular muscles, the accommodative system, and the optical media, essentially gathers photopic information and converts this information to electrical energy. The contribution of vision in balance is primarily through the vestibulo-ocular reflex (VOR), which is dependent on a stable, bifoveal retinal image. Therefore, diplopia is an obvious cause of visual confusion related to the dysfunction of the peripheral component. However, clinical experience reveals more subtle visual and ocular motor dysfunctions, such as heterophorias and accommodative-vergence dysfunctions, which are often associated with vestibular symptoms. In a broad sense, any mismatch of visual information could potentially exacerbate a vestibular problem. Many individuals have moderate vertical and horizontal heterophorias that may have been adequately compensated for most of their lives. However, an illness or an event, such as a TBI, can result in a breakdown of control of fusional vergence. This decompensation of binocularity, in addition to the mismatching of afferent information, will affect the VOR and ultimately balance negatively.

Vision's central component is organized through two main and separate systems, parvocellular (P) and magnocellular (M), respectively. Table 1 compares the characteristics of these systems. Simply, the M System is important in providing information about where one is in space and where one is looking, while the P system provides detailed information about the object of regard.

The P system transmits central foveal vision and is important for clear and precise vision. These nerve fibers start at the retina and travel via the optic nerve, the optic chiasm, optic tract and ultimately synapse at the lateral geniculate. They then proceed to the optic radiations, to the primary visual cortex in the occipital lobes and then project to the temporal brain region for the associated visual cortex (Skarf, Glaser, Trick; 2000; Barton, Barton, Rizzo, 2000; Miller and Newman, 1998; Felleman and Van Essen, 1991; Kaas, 1989).

The M system is involved primarily with the processing of aspects of spatial orientation and information about where one is in space, thereby contributing to balance, movement, coordination and posture. Some of the peripheral retinal fibers are

TABLE 1 Characteristics of transient and sustained subsystems

| Magnocellular | Parvocellular |
|---|---|
| 1. Most sensitive to low and middle spatial frequencies: large overall shapes. | 1. Most sensitive to high spatial frequencies: fine detail. |
| 2. High sensitivity to contrast. | 2. Low sensitivity to contrast. |
| 3. Peripheral vision dominant. | 3. Central (foveal) vision dominant. |
| 4. Responds to onset and offset of stimulus. Short response persistence (transient). | 4. Responds during and after stimulus presentation. Longer response persistence. |
| 5. Most sensitive to high temporal frequencies. | 5. Most sensitive to low temporal frequencies. |
| 6. Responds quickly to moving targets (early warning). | 6. Sensitive to stationary or slow-moving targets. |
| 7. Sensitive to short wavelengths (e.g., blue). | 7. Sensitive to longer wavelengths (e.g., red). |
| 8. Global analysis of incoming visual information. | 8. Identification of shapes and patterns. |
| 9. Involved in perception of depth, flicker, motion, brightness, discrimination. | 9. Involved in processing color information. |
| 10. Prepares visual system for the input of slower detailed information that follows. | 10. Responds subsequent to transient output and is dependent upon transient output. |

Reprinted with permission from Solan H.A., Transient and sustained processing: a dual subsystem of theory of reading disability. *Journal of Behavioral Optometry*. 5:151, 1994.

directed primarily to the midbrain, where they synapse at the lateral geniculate body and then project to the superior colliculus, which is important for integrating posture, movement, and orientation to positional space (Skarf, Glaser, Trick; 2000; Barton, Barton, Rizzo, 2000; Felleman and Van Essen, 1991; Kaas, 1989). Other peripheral retinal fibers continue to the occipital cortex and then project to the temporal and parietal areas, which recently have been found to be associated with visually-directed motor performance (Goodale and Humphrey, 1998).

The superior colliculus receives visual, auditory, and somatosensory stimuli and is involved in reflex turning of the head towards the source of the stimuli. Visual information originates both directly from the eyes, as well as the visual cortex. Auditory and somatosensory stimuli reach the superior colliculus via projections from the inferior colliculus and spinal cord, respectively. Since the superior colliculus receives fibers from the optic tract, occipital cortex, and spinotectal tract, it becomes linked with the kinesthetic, proprioceptive, vestibular, and tactile systems. Finally, appropriate coordinated head and body postural reflexes are generated as information flows across the vestibulocerebellar and vestibulospinal tracts (Skarf, Glaser, Trick; 2000; Barton, Barton, Rizzo, 2000; Miller and Newman, 1998; Felleman and Van Essen, 1991; Kaas, 1989).

Vestibular signals that are produced as a consequence of reflex head movements (i.e. VOR) are evaluated by integrating mechanisms and rendered inappropriate. The suppression of the VOR allows the generation of appropriate saccade or pursuit eye movements. It can be appreciated that the mismatching of visual information with other elements of the sensory motor feedback system could otherwise cause one to perceive an image as jumping and moving with the shifting of our eyes.

## OPTOMETRIC CONTRIBUTION TO MANAGEMENT OF VESTIBULAR DISORDERS

The maintenance of a stable spatial world is significantly influenced by how visual information is processed and integrated with the vestibular and somatosensory systems. The VOR is important for maintaining a stable visual spatial world when head and body movements are involved and, therefore, any visual information mismatch may exacerbate balance complaints. Therefore, the role of optometry is to assess the quality of the visual input, as well as its integration with the vestibular processing system, being aware that small refractive errors, fixation anomalies, unstable fusion, and other ocular conditions, which may affect the visual input as well as the VOR, could significantly exacerbate symptoms of disequilibrium.

Those with vestibular and balance problems would benefit from the full scope of behavioral optometry, which encompasses the management and treatment of ocular disease to optical strategies and visual therapy (Padula, 2000). The sections that follow will outline and discuss the key elements related to the diagnosis and treatment of vision conditions associated with and exacerbating the symptoms in this population. It is beyond the scope of this article to detail the diagnostic and management procedures that optometrists perform, but this information can be found in other reference books (Rosen, Cohen, Trebing, 2001).

Among those with vestibular dysfunction, certain vision and optical characteristics, visual sensory motor symptoms and signs, visual perceptual conditions, and systemic or neurological conditions are more common (see Tables 2-5). In addition to being aware of these characteristics, the actual vision examination is tailored as outlined below.

## OPTOMETRIC EVALUATION

A. History

One of the commonly-accepted concepts is that symptoms of disequilibrium and balance difficulties are a result of the inability of the brain to adjust to a mismatch of information between the auditory, visual and proprioceptive processing system. It is the author's clinical experience that a large percentage of individuals with disequilibrium have binocular vision problems, refractive anomalies, and other ocular motor and visual disturbances, which affect the integrity of the visual input. Often, one is not aware of these problems or has learned to compensate for them until an additional problem occurs, after which a decompensation of vision function is evident and accompanied by symptoms of disequilibrium. A careful review of social, medical and ocular histories is important. The following areas are reviewed:

1. Medications: stress-reduction medications often impair accommodation.
2. History of virus infection or severe bacterial infection: certain antibiotics, such as Gentamicin, may be toxic to the vestibular system, depending upon dosage.
3. History of recent stressful situations: increased stress levels are often associated with the onset of vestibular symptoms.
4. History of acquired brain injury, including TBI: this event may serve to decompensate one of the three systems contributing to balance.
5. Ocular history: inquire about a prior history of binocular vision, reading, or focusing problems.
6. History of other types of rehabilitation: note the types of therapy, especially balance, and the degree of progress made.

| TABLE 2 | Vision and Optical Problems Associated With Vestibular Problems |
|---|---|
| | • Anisometropia<br>• Uncorrected astigmatism<br>• Uncorrected hyperopia<br>• Peripheral distortions with progressive lenses<br>• Glare, flickering light, and reflections |

| TABLE 3 | Sensorimotor Vision Problems Associated With Vestibular Symptoms |
|---|---|
| | • Ocular motor anomalies<br>• Sluggish accommodation<br>• Vertical heterophoria<br>• Esophoria at distance<br>• Intermittent strabismus<br>• Convergence insufficiency<br>• Restricted fusional vergence ranges |

| TABLE 4 | Visual Processing Problems Associated With Vestibular Problems |
|---|---|
| | • Visual sequencing difficulty<br>• Figure ground difficulty<br>• Visual closure difficulty<br>• Visual spatial relations difficulty<br>• Visual agnosia<br>• Dorsal and ventral stream of visual perceptual processing |

| TABLE 5 | Systemic and Neurological Conditions Associated With Vestibular Problems |
|---|---|
| | • Traumatic brain injury<br>• Stroke<br>• MS<br>• Parkinson's Disease; Progressive Supranuclear Palsy<br>• Meniere's<br>• Drug Toxicity; most common Gentamicin<br>• Autoimmune disease |

7. Review in detail visually-related symptoms

B. Visual acuity assessment
Accurate visual acuity measurement requires observing for subtle ocular motor deficits (such as micro-nystagmus, saccadic intrusions, drift) and signs of distortions and scotomas since these may impact the VOR as well as perception of space. Near visual acuity should be measured at the individual's usual or habitual reading distance.

C. Refractive Analysis
The refractive assessment is critical because adequate visual sensory motor vision function requires an image on each eye that is reasonably equal in clarity. Therefore, the person's awareness and reaction to lens changes should be observed prior to prescribing for any refractive errors evident, including low hyperopia and astigmatism, to optimize clarity in each eye to the same degree. In terms of near vision, lag of accommodation and relative accommodation are important to measure.

D. Assess the level of sensory motor processing
With respect to ocular motor testing of pursuit, saccades, and fixation, the individual should be asked whether there is dizziness, vertigo, or disequilibrium experienced while following the target. Any ocular misalignment evident on pursuit testing binocularly should be noted as comitant or non-comitant, along with any restriction of ocular motility. Saccadic intrusions and nystagmus evident upon motility testing, especially if more pronounced in one position of gaze than others, should also be recorded. Testing global saccadic speed, accuracy, and efficiency should be performed, with any reports of dizziness, nausea, and vertigo noted.

Ocular alignment is assessed using the cover test, while observing the quality of fixation and the speed of sensory motor recovery. Any ocular misalignment should be evaluated in all positions of gaze at distance, as well as near. Subsequently, fusion under binocular conditions is measured with relative fusional vergence ranges, the near point of convergence, and auxiliary tests for sensory fusion and stereopsis. Additional specialized techniques can address visual sensory motor function, and its impact on spatial localization as well as fusion, in free space as well as in instruments.

E. Visual perceptual processing
Visual perceptual processing should be assessed with respect to the level of visual figure ground analysis ability, the level of visual sequential memory processing ability, the speed of visual closure processing, the speed and span of visual perception, and the ability to process both simultaneous and sequential visual information.

F. Ocular health evaluation
The accepted protocol for a comprehensive primary care eye examination is performed including confrontation visual field testing, color vision testing, pupil testing, tonometry, and evaluation of the anterior and posterior segments with a dilated fundus examination. Areas that require special attention are pupil function, corneal integrity due to the high occurrence of dry eye in this population, and gross functional visual field awareness using confrontation visual fields as a good screening procedure.

## TREATMENT GOALS FOR VESTIBULAR DISORDERS

The management of this population entails the application of the full scope of optometry ranging from managing ocular health problems such as dry eye syndrome to optical applications, low vision rehabilitation, and visual therapy.

A. Optical Treatment Modalities
Providing the best quality and most stable visual input is desired. This is achieved by prescribing the most appropriate optical correction. In addition, prescribing separate distance vision and separate near vision corrections, rather than a progressive multifocal lens, avoids the peripheral distortions inherent in that lens design, which would otherwise trigger symptoms of disequilibrium. Tints and anti-reflective coatings may be suggested to reduce symptoms of photosensitivity and glare. Incorporation of a light blue filter may enhance magnocellular processing.

Judicious prescribing of fusional prism lenses implies that one prescribes fusional prism when indicated, typically for large magnitude ocular misalignments and vertical deviations. Yoked prism systems may provide beneficial results for gaze restrictions, visual field defects, and certain visual perceptual processing deficits.

B. Optometric Visual Therapy
Two concepts are important in the rehabilitative model and are therefore applicable to visual rehabilitative therapy: 1) the multiple layering of information processing and 2) redundancy of the physiological and neurological system, which is the concept of neural plasticity. When possible, the optometrist should strive to incorporate certain principles in visual therapy procedures in order to enhance neuro-physiological changes, which are outlined in Table 6.

## TREATMENT GOALS FOR VISION THERAPY FOR VESTIBULAR DISORDERS

A. Enhance the stability of the visual input system
Developing and enhancing accurate saccades involves motor planning. To improve motor planning, techniques involving stimulus-generated saccades associated with high level visual processing tasks such as figure ground and visual closure skills are beneficial. Once motor planning is more pronounced and accurate, integrating the central saccadic fixation performance (parvocellular) with balance, motor control, and peripheral awareness (magnocellular) can occur. In addition to stabilizing fixation and saccades, accommodation must be maximized, based on age-related normative data.

TABLE 6 Visual Therapy Principles to Enhance Neuro-physiological changes

- Repetition
- Feedback, both motor and sensory.
- Multi-sensory tasks especially those which require visuomotor performance
- Tasks which require a level of problem solving
- Using techniques which have highly motivating detailed, central visual stimuli, while filtering peripheral distraction
- Tasks which require a motor response to a visual mismatch
- Procedures which require active participation by the patient

B. Develop a stable binocular vision system
The ultimate goals of a stabilized binocular vision system are accommodative and vergence flexibility, rapid recovery of fusion, central fusional vergence stability, and stable fusional vergence associated with head and body movement.

C. Facilitate and enhance a coordinated output system
Developing balanced peripheral and central fusional vergence facility associated with high level visual–motor planning is desirable, especially in conjunction with enhanced speed of fusion recovery with rapid changes of relative divergence and convergence. Finally, the goal of stabilizing fusional vergence under static and dynamic conditions can occur.

D. Enhance the speed and facility of visual perceptual processing
The goal is to enhance or optimize the speed and span of perception, the accuracy and level of figure-ground analysis, the level and speed of visual closure, and the speed and accuracy of visual

sequencing.

E. Visual field deficits
Visual field loss and visual distortion are special problems often associated with and/or exacerbating vestibular problems. Conditions such as hemianopia, scotomas, and morphopsia can be addressed with yoked prism systems, visual rehabilitation, and low vision rehabilitation therapy and other optical devices (Cohen, 2003).

## Conclusion

Individuals with TBI frequently report dizziness, disequilibrium, and vertigo. Consequently, they may experience extreme difficulty with balance and movement, as well as their perception of visual space. In many instances, vestibular rehabilitation may be indicated and, therefore, recommended. However, since vestibular rehabilitation typically requires an intact ocular motor system, if individuals have a compromised visual sensory motor system, the vestibular rehabilitation, in isolation, may produce limited therapeutic benefit. Such individuals with TBI, vestibular dysfunction, and visual sensory motor impairment may experience difficulty in environments with excessive visual stimulation (i.e., a grocery store or shopping mall). This unsteadiness or disequilibrium exemplifies a vestibular dysfunction resulting from a VOR disturbance related to an inner ear problem in conjunction with impaired visual sensory motor function. In such cases, an optometric evaluation and subsequent vision therapy would serve to stabilize vergence ocular motility and accommodation under static, as well as dynamic, conditions, making it possible to perform and benefit from the gaze stabilization techniques in vestibular rehabilitation. For those with compromised visual sensory motor function, the combination of optometric vision therapy and vestibular rehabilitation frequently results in a significant reduction or complete elimination of the visual and vestibular symptoms.

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Dr. Allen H. Cohen is a professor of optometry at the SUNY-State College of Optometry. He teaches optometric interns and residents at the Northport VA Medical Center in Northport, N.Y., where he has been Chief of the Optometry Service since 1976. In addition to his teaching responsibilities, Dr. Cohen also maintains a private optometric practice, which predominantly serves individuals with acquired neurological deficits. Dr. Cohen is a Fellow of the College of Optometrists in Vision Development and a Diplomate of the American Academy of Optometry in the area of binocular vision and perception. He has published several papers and textbook chapters, and lectures extensively nationally and internationally

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# The Rehabilitation of Vergence and Accommodative Dysfunctions in Traumatic Brain Injury

by Robert S. Fox O.D., FCOVD

## INTRODUCTION

Diplopia and blurred vision, either constant or intermittent, are two of the most common symptoms reported by individuals with traumatic brain injury (TBI). The impact of these symptoms during the course of rehabilitation is often significant and may interfere with their overall rehabilitation. Individuals with TBI may experience difficulty when participating or the inability to participate during a wide array of visually-guided activities, which are common in physical, speech, cognitive, and occupational therapies. These vision symptoms may also impact visually-guided aspects of quality of life negatively. Finally, symptoms of diplopia and blur are caused by deficits in vergence and accommodation, which often respond favorably to optometric intervention, thereby resulting in a reduction of symptoms and increased comfort for the individual with TBI.

This paper defines and describes vergence and accommodative conditions, which are typical following TBI. An optometric vision rehabilitation approach is also outlined for these vision dysfunctions. Two case presentations serve to exemplify optometric vision rehabilitation with TBI.

## HORIZONTAL VERGENCE EYE MOVEMENTS

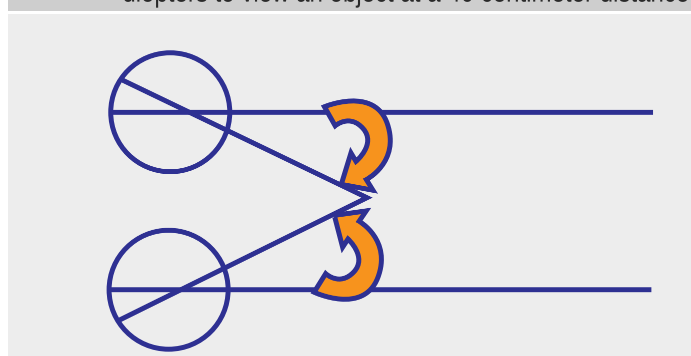
### Diagnosis and Symptomatology for Horizontal Vergence Dysfunctions

Vergence eye movements refer to the coordinated eye movements under binocular viewing conditions, which are required to keep both eyes simultaneously aligned at any given target. When the two eyes are perfectly aligned at the same time, the brain is able to combine the two images together into one image through a process called fusion. When fusion is not achieved, but the images are still simultaneously perceived, the result is diplopia, which is a common symptom with TBI.

There are three types of vergence eye movements: horizontal, vertical, and cyclo-rotary. Only horizontal vergence dysfunctions, which are most amenable to vision rehabilitation and have a better prognosis, will be discussed in this paper. There are two types of horizontal vergence: convergence and divergence. Anomalies of either convergence or divergence may result in a variety of symptoms such as headaches, diplopia, blurred vision, dry eye, reading problems, reduced depth perception, and balance problems (Cohen and Soden, 1981; Padula, Shapiro, and Jasin, 1988; Krohel et al., 1986; O'Dell M.W., Bell K.R., Sandel M.E., 1988; Scheiman and Wick, 2002; Zost, 2001). Since glare and dry eye may disrupt fusion many individuals with vergence dysfunction may also be very photosensitive. Studies are ongoing to investigate the relation between the use of lubricating ocular solutions and suspensions in reducing symptoms of dry eye and photosensitivity, as well as increasing reading ability and comfort, in individuals with TBI (Jackowski, 2004).

During convergence, the eyes move inward from their near-parallel position of rest. Physiologically, the medial recti extraocular muscles are stimulated while the lateral recti extraocular muscles are inhibited. As shown in figure 1, the eyes must move inward approximately 15 prism diopters (pd) (7.5 pd for each eye) to permit fusion at a normal reading distance of 40 centimeters (cm). The near point of convergence (NPC) is a standard test to determine the integrity of convergence ability for near vision tasks. While slowly moving a target towards a person who is wearing the appropriate near vision spectacle correction with both eyes open, the examiner observes and records the distance that the person objectively is no longer fusing the target or subjectively reports diplopia. Then the examiner slowly moves the target away from the person and records the distance that single vision is reported again or the eyes re-align objectively.

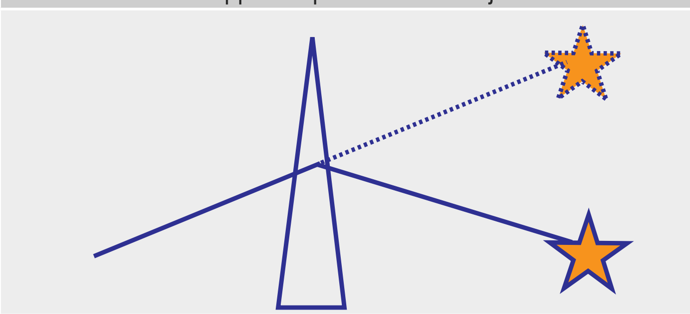
FIGURE The eyes converge inward a total of 15 prism diopters to view an object at a 40 centimeter distance



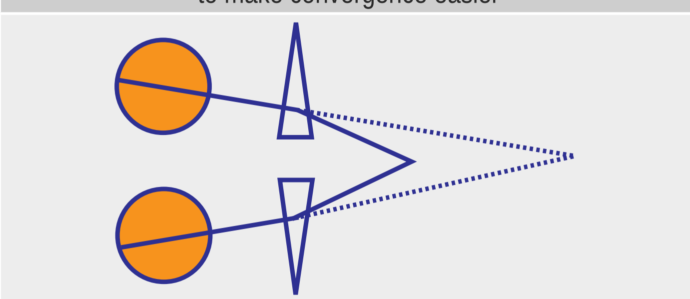
All near vision tasks, including reading, writing, eating, and computer use, require appropriate vergence to be achieved and sustained for the task to be performed comfortably under binocular viewing conditions. If convergence cannot be achieved or sustained effectively, the resultant vision condition may be either a convergence insufficiency, where the ocular alignment is beyond the plane of regard, or a convergence excess, where ocular alignment is closer than the plane of regard. Convergence insufficiency is the most common of the vergence deficits seen in the TBI population (Suchoff et al., 1999).

During divergence, the eyes move from a convergent alignment to a near-parallel position, which is most evident when viewing distant objects. There are occasions when one's eyes align appropriately at near but are unable to achieve and sustain parallel alignment when viewing distant objects binocularly. The resultant vision condition may be either a divergence insufficiency, where the ocular alignment is closer than the plane of regard, or a divergence excess, where the ocular alignment is beyond the plane of regard. While convergence dysfunctions are more typical in the TBI population, difficulties with divergence may also arise (Suchoff et al., 1999).

FIGURE A prism bends light to shift the apparent position of an object



Fusional base-in prism is used to make convergence easier



When evaluating vergence, a cover test is performed to measure the magnitude and direction of any ocular misalignment, as well as to determine whether a heterophoria or a strabismus is evident (Scheiman and Wick, 2002). A person is said to have an exophoria if the eyes tend to move outward even though fusion is maintained. Esophoria refers to a tendency for the eyes to turn inward while fusion is maintained. If the eyes are misaligned in a way that is evident to the observer either intermittently or constantly regardless of the viewing distance, then an actual eye turn, or strabismus, is said to be present. Individuals with acquired strabismus typically report diplopia. If the deviation is outward, it is known as an exotropia, while an inward deviation is an esotropia. Outward, or exo, deviations are much more common than inward, or eso, deviations, with a prevalence of almost 41% relative to less than 2%, respectively (Suchoff et al., 1999).

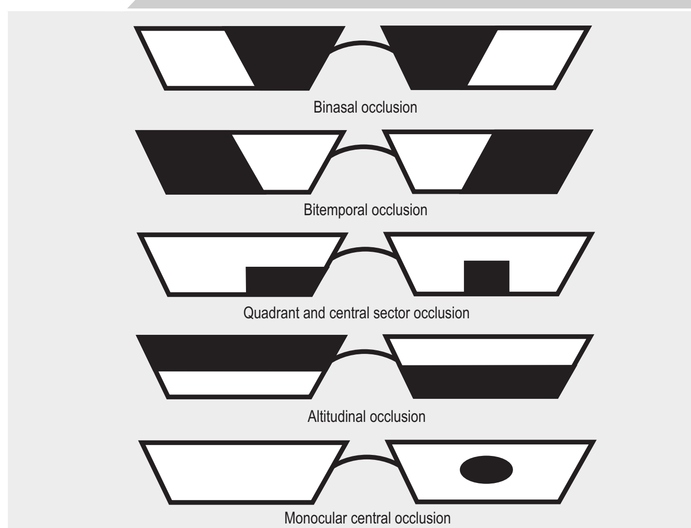
## Treatment Options for Horizontal Vergence Dysfunctions

The treatment of horizontal vergence eye movement deficits has many components, which may include application of lenses, prisms, selective occlusion, and/or optometric vision therapy (Kapoor and Ciuffreda, 2002; Scheiman and Wick, 2002). Lenses are an important consideration with TBI. Some individuals may experience relief from symptoms through using glasses for reading when convergence is compromised for near vision tasks. Reducing the effort required to focus at near often enhances the ability to achieve, as well as sustain, near convergence and stable fusion. Single vision reading glasses or bifocal lenses may assist those with TBI greatly. In addition, application of tinted lenses may improve comfort, by reducing light and glare sensitivity significantly.

Prisms are optical aids with a base and an apex. They bend light so that the perceived image by the person wearing the prisms is moved in the direction of its apex (see figure 2). This different perception of image location with prisms is useful in managing symptoms of constant or intermittent diplopia. Prism can be prescribed in a range of magnitudes of prism diopters and may be oriented in any direction to compensate for ocular misalignment. Small amounts of prism can be incorporated into spectacle lenses to facilitate more accurate, efficient, and stable fusion. For example, as shown in figure 3, prism with the bases oriented inwards, or towards the nose for each eye, may aid in fusing the images binocularly in the presence of a moderate or significant exo deviation either at near or far viewing distances. Optometrists may use a combination of prisms in different directions and magnitudes for each eye to aid in achieving fusion.

There are occasions where fusion cannot be achieved with the application of lenses and/or fusional prisms. In such cases, selective occlusion may be required to eliminate the symptom of diplopia present under binocular viewing conditions. In selective occlusion, only part of the visual field is blocked, as opposed to full occlusion (patching). There are many ways to occlude vision, with each being dependent upon the specific ocular misalignment and associated restriction in extraocular motility (see figure 4). The most commonly-used forms of selective occlusion are monocular central occlusion (spot patch) and binasal occlusion.

FIGURE Methods of selective occlusion

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When using a spot patch, a small round piece of translucent tape is used to block the visual axis of the deviating eye, which effectively eliminates the diplopia in the central visual field while retaining all aspects of peripheral vision. Since peripheral vision is important in balance, posture, and navigation, the spot patch is usually more comfortable than completely occluding the deviating eye. Application of the spot patch frequently results in immediate relief and is most commonly used when there is marked restriction of extraocular motility of one of the eyes.

Binasal occlusion, using translucent tape to block part of the nasal part of each spectacle lens, is also valuable in reducing the discomfort and diplopia associated with poor vergence eye movements. The smaller common field of vision for the two eyes greatly reduces the diplopia perceived. Also, from the viewpoint of the person being occluded, the translucent tape forces the eyes to look more centrally, rather than too far towards the nose, which promotes better fusion and sustained binocular vision.

Lastly, and perhaps most importantly, optometric vision therapy with TBI is used to help regain the ability to use the two eyes together with accuracy, efficiency, and sustainability. While optometric vision therapy is beneficial for horizontal vergence dysfunctions, its efficacy has been best researched and established for the treatment of convergence insufficiency in individuals without TBI (Scheiman et al., 2005, Scheiman and Wick, 2002; Cohen, 1988; Ciuffreda, 2002; Cohen and Soden, 1984). In non-brain-injured individuals, symptoms and signs of horizontal vergence dysfunctions are either reduced or often eliminated by a regimen of vision therapy lasting 2 to 6 months in duration, with weekly in-office vision therapy sessions. Though approaches may vary, most therapy techniques rely on the gradual improvement of motor fusion ranges, response to sensory fusion stimuli, and the sustainability of the integrated, vision sensory motor response over time.

With TBI, the efficacy of vision therapy has been reported in the form of numerous case reports (Krohel et al., 1986; Ludlam, 1996; Berne, 1990; Hellerstein and Freed, 1994; Ciuffreda et al., 1996; Kapoor, Ciuffreda, and Han, 2004). In addition, vision therapy with TBI occurs more gradually and, therefore, has a longer duration. Many experience great discomfort as the vergence demand (either convergence or divergence) is increased during therapy. Care must also be taken not to fatigue the person resulting in an early end for a therapy session. Overall, though, vergence therapy techniques are very helpful with those with TBI who have a horizontal vergence dysfunction. These rehabilitative techniques, in conjunction with lenses, prisms, and selective occlusion, permit most to achieve and sustain comfortable, single vision under binocular viewing conditions.

## ACCOMMODATION

### Diagnosis and Symptomatology of Accommodation

Accommodation is the physical act of acquiring a clear retinal image. There is a physiological, age-related loss of this ability to change focus or accommodate called presbyopia. Aside from presbyopia, it is possible to have inadequate accommodation in a person who is under the age of 40 years. In these pre-presbyopic persons, their inadequate ability to change focus is termed accommodative insufficiency.

Accommodative insufficiency is common with TBI and often results in reduced near visual acuity or the inability to sustain clear vision when viewing a near vision target. The symptoms of poor accommodation include blurred vision, headaches, eyestrain, squinting, diplopia, and reading problems (Scheiman and Wick, 2002). It has been reported that 10% of individuals with TBI have accommodative problems (Suchoff et al., 1999).

Accommodative testing is a standard part of the neuro-optometric examination. While wearing one's distance spectacle correction, the amplitude of accommodation is measured one eye at a time (i.e., monocularly) by either using lenses (measured in diopters) that increase accommodative demand, or by gradually bringing near vision material closer to the individual, until the first sustained blur is evident. This maximum extent of the accommodative demand in diopters is the measure or amplitude of one's monocular focusing ability before losing image clarity (monocular accommodative amplitude).

### Treatment Options for Accommodative Dysfunctions

Treatment options for accommodative dysfunctions include the application of lenses with or without conjunctive vision therapy (Kapoor and Ciuffreda, 2002; Scheiman and Wick, 2002). Unlike the presbyope, who follows a very predictable, age-related progression of near vision spectacle power, individuals with TBI require more careful testing to determine the optimal lens for prolonged near vision tasks. In addition to measuring the amplitude of accommodation, extensive near vision tests including near point retinoscopy to measure the lag of accommodation, as well as measures for ranges of positive relative accommodation (PRA) and negative relative accommodation (NRA), are necessary to find a lens that provides optimum comfort and clarity for prolonged near vision tasks. Lenses of very mild powers can often bring tremendous relief to these individuals.

TABLE 1 Vision sensory motor findings for LS (Date of Birth: 02/19/1947)

| Vision Sensory Motor Parameter | | Pre-Therapy | | 5 months Post-Therapy | |
|---|---|---|---|---|---|
| Refraction/spectacle correction | | OD +1.50-6.00x015 | | OD +0.75-6.00x155 | |
| | | OS +1.50-6.00x015 | | OS +0.75-6.00x155 | |
| Confrontation visual field testing | | OD Mild Constriction | | OD Full all meridia | |
| | | OS Mild Constriction | | OS Full all meridia | |
| Extraocular motility testing | | OD Full, uncomfortable | | OD Full | |
| | | OS Full, uncomfortable | | OS Full | |
| Best correct distance visual acuity | | OD 20/30 | OS 20/30 | OD 20/30 | OS 20/30 |
| DCT | | 6 exophoria | | 4 exo | |
| Distance NFV | Distance PFV | X/6/4 | X/12/8 | X/6/4 | X/12/8 |
| Lag of accommodation | | OD +2.25 | OS +2.25 | OD +2.25 | OS +2.25 |
| Best corrected near visual acuity | | OD 20/25 | OS 20/25 | OD 20/25 | OS 20/25 |
| NPC | | 2"/4" | | to the nose | |
| NCT | | 6 exophoria | | 6 exophoria | |
| Near NFV | Near PFV | X/12/8 | X/8/4 | X/12/8 | X/8/4 |
| NRA | PRA | +0.50 | -1.25 | +0.50 | -1.00 |

Sensory motor vision data for LS are presented. Refraction/spectacle correction, lag of accommodation, and relative accommodation (NRA and PRA) are noted in diopters. Distance cover test (DCT) and near cover test (NCT) are measures of ocular alignment, which are recorded in prism diopters. Fusional vergence ranges, including negative fusional vergence (NFV) and positive fusional vergence (PFV) at far as well as near viewing distances, are also noted in prism diopters. Near point of convergence (NPC) is recorded in inches from the nose of the individual being tested.

While the treatment of accommodative insufficiencies primarily involves the use of near vision (reading) spectacle correction, which is distinct from the person's distance vision spectacle correction, the addition of optometric vision therapy alone or in conjunction with near vision lens application may also help to regain the ability to accommodate (change and sustain focus) in an age-appropriate manner. Once again, the efficacy of accommodative therapy has been established in the non-TBI population (Scheiman and Wick, 2002; Cohen, 1988; Ciuffreda, 2002). While research is still needed in the TBI population, there are clinical case reports noting vision therapy's efficacy in this population (Berne, 1990; Hellerstein and Freed, 1994; Freed and Hellerstein, 1997).

Most accommodative vision therapy techniques involve developing ranges of one's ability to rapidly change, as well as, sustain accommodation using lenses that increasingly stimulate and relax accommodation or techniques in free space that serve to increase and reduce the accommodative demand by looking between targets at varying distances. As with vergence training, throughout vision therapy there is a gradual, progressive increase in difficulty of the techniques, with respect to accommodative ability, flexibility, and sustainability.

TABLE 2 Vision sensory motor findings for RC (Date of Birth: 12/06/1950)

| Vision Sensory Motor Parameter | | Pre-Therapy | | 6 months Post-Therapy | |
|---|---|---|---|---|---|
| Refraction/contact lens correction | | OD -3.00 (contact lens) | | OD -3.00 | |
| | | OS -3.00 (contact lens) | | OS -3.00 | |
| Confrontation visual field testing | | OD full all meridia | | OD full all meridia | |
| | | OS full all meridia | | OS full all meridia | |
| Extraocular motility testing | | Full with monocular testing, and diplopia on binocular testing | | Full with monocular testing and minimal diplopia in extreme lateral gaze on binocular testing | |
| Best correct distance visual acuity | | OD 20/20 | OS 20/20 | OD 20/20 | OS 20/20 |
| DCT | | 4 exophoria | | 1 exophoria | |
| Distance NFV | Distance PFV | X/4/0 | X/6/3 | X/6/2 | X/24/6 |
| Lag of accommodation | | OD +1.50 | OS +1.50 | OD +2.00 | OS +2.00 |
| Best correct near visual acuity | | OD 20/20 | OS 20/20 | OD 20/20 | OS 20/20 |
| NPC | | 8"/16" | | 2"/4" | |
| NCT | | 14 exophoria | | 5 exophoria | |
| Near NFV | Near PFV | X/12/4 | X/-1/-5 | X/11/5 | X/24/4 |
| NRA | PRA | +0.75 | -0.25 | +0.75 | -0.75 |

Sensory motor vision data for RC are presented. Refraction/contact lens correction, lag of accommodation, and relative accommodation (NRA and PRA) are noted in diopters. Distance cover test (DCT) and near cover test (NCT) are measures of ocular alignment, which are recorded in prism diopters. Fusional vergence ranges, including negative fusional vergence (NFV) and positive fusional vergence (PFV) at far as well as near viewing distances, are also noted in prism diopters. Near point of convergence (NPC) is recorded in inches from the nose of the individual being tested.

## CASES

### Case #1: LS

LS is a 54-year-old female, who suffered a TBI secondary to being in a motor vehicle accident. She presented wearing a bifocal spectacle correction, but she had many spectacle prescriptions through the years and was never satisfied with any of them. Her visually-related symptoms included blurred vision, eyestrain, some doubling around the edges of objects, frequent headaches, and reading problems related to the print running together on the printed page.

Optometric testing revealed a visual acuity of 20/30 in each eye at both distance and near for LS with her current glasses, which compensated for a large amount of astigmatism. Though her NPC revealed adequate convergence (5 cm), additional vergence testing showed a moderate amount of exophoria at both far and near with poor compensatory convergence motor fusion ranges. A diagnosis of exophoria was made and new eyeglasses, with small amounts of base-in prism (0.75 pd) incorporated in conjunction with her current lens powers, were prescribed for full time wear.

LS returned three months later for a re-evaluation and was very satisfied with her vision. She reported the elimination of diplopia, greater ease when driving, a slight reduction in headaches, and a great improvement in her reading ability and comfort. Although the vergence testing at LS's three-month re-evaluation was relatively unchanged from the initial examination, the fusional prism in her near vision spectacles compensated for the vergence dysfunction, thereby reducing her symptoms and increasing comfort and function for basic activities of daily living. At her five-month follow-up visit, she continued to report a significant reduction of headaches and vision symptoms, resulting in her increased comfort with routine activities including reading for pleasure. Table 1 presents changes in LS's vision sensory motor data from pre-therapy to 5 months post-therapy.

### Case #2: RC

RC, a 51-year-old male, was referred for optometric evaluation by his primary care optometrist who had detected deficits in convergence. RC worked as an industrial hygienist and had suffered a TBI when his van rolled over in a motor vehicle accident. His vision symptoms were specifically related to reading and included diplopia, loss of place, intermittent blur, and headaches. He wore contact lenses for myopia and used over-the-counter reading spectacles for close work. He was also receiving cognitive therapy by a neuro-psychologist for memory deficits.

RC had a number of significant findings on optometric testing. During eye movement testing, he reported diplopia whenever the target he was tracking moved more than 10 degrees away from primary gaze. He presented with a receded NPC with the break and recovery of fusion being 8 inches and 16 inches, respectively, with normal values being 2 inches and 4 inches, respectively. He had an exophoria at near of 14 prism diopters and his motor fusion ranges were severely limited with RC having almost no ability to maintain fusion at near. A diagnosis of convergence insufficiency was made and RC was started on an office-based program of vision therapy with the goals of improving motor and sensory fusional vergence, thereby resulting in sustainable, clear and single vision for prolonged near vision tasks.

After six months of vision therapy RC showed a considerable reduction in the frequency and intensity of headaches and diplopia, such that they only occurred when extremely fatigued. Using his reading glasses in conjunction with his contact lenses for near vision tasks, he reported being able to read comfortably, despite some persisting difficulty with memory and comprehension. Near testing revealed an NPC of 2 inches/4 inches and an exophoria of 5 prism diopters, both of which are within the normal range for near vision testing. His sensory motor fusional ability was adequate (see table 2 for changes in RC's vision sensory motor data pre- and 6 months post-therapy). He was discharged from office-based therapy and placed on a home maintenance program of vision therapy at that time.

## CONCLUSIONS

With the increased prevalence of accommodative and vergence problems in the TBI population, knowledge of their signs and symptoms, as well as possible treatment options, is important. Subtle deficits in vergence and accommodation can be extremely debilitating whether or not blur or diplopia is reported. With TBI, verbal or non-verbal, the level of function in the accommodative and vergence systems can be assessed and be followed by appropriate treatment recommendations, including the application of lenses, prisms, filters, and vision therapy. While these treatment options are not new to optometry, they are recent additions to the area of TBI rehabilitation.

Given the inter-disciplinary nature of TBI rehabilitation, the assessment and management of vision deficits has become increasingly more important. Furthermore, optometrists are becoming more visible members of this rehabilitation team by offering vision rehabilitation services, which may reduce significantly the symptoms of the individual with TBI. This reduction in vision symptoms may consequently enhance and expedite the overall progress of all other aspects of TBI rehabilitation, as well as quality of life.

## ABOUT THE AUTHOR

Robert S. Fox, O.D., F.C.O.V.D., holds a B.S. degree in Biomedical Engineering from Rensselaer Polytechnic Institute, and a Doctor of Optometry degree from the SUNY-State College of Optometry. He also completed a residency in Rehabilitative Optometry at the Northport V.A. Medical Center. Dr. Fox is a fellow of the College of Optometry in Vision Development and has a private practice in Schenectady, NY, which is limited to developmental and rehabilitative optometry. In addition, he is on staff at the Sunnyview Rehabilitation Hospital in Schenectady, and the Eddy-Cohoes Rehabilitation Center in Cohoes, NY. A frequent speaker on the topics of vision therapy and vision rehabilitation, Dr. Fox resides in Niskayuna, NY with his wife, Randy, and daughters, Sharon and Joanna.

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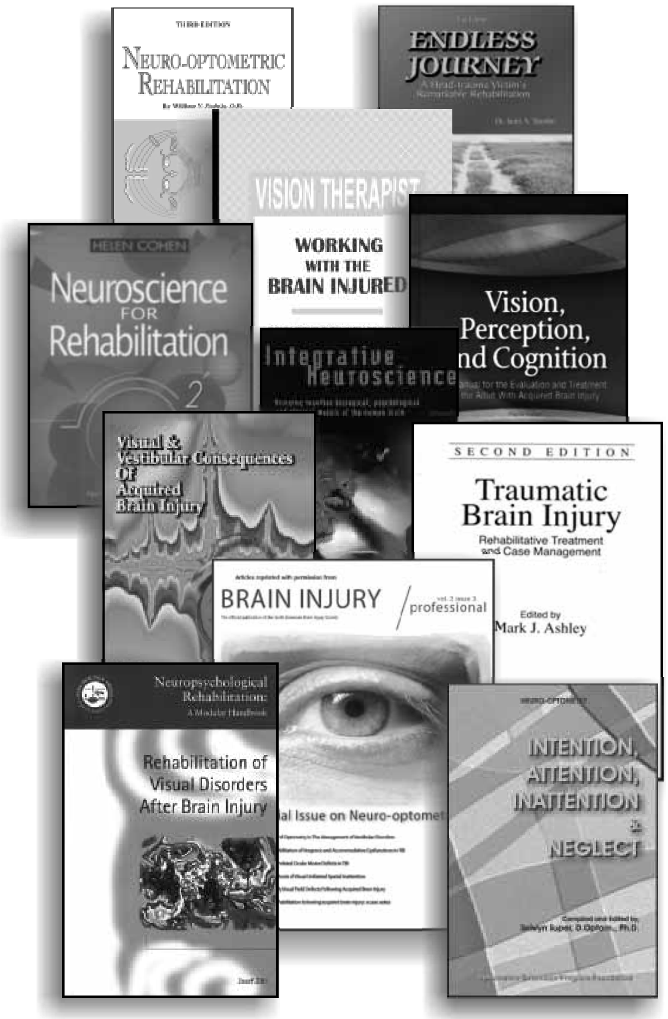
# Recommended Reading

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# Reading-related ocular motor deficits in traumatic brain injury

by Kenneth J. Ciuffreda, O.D., Ph.D., F.A.A.O.
Neera Kapoor, O.D., M.S., F.A.A.O.
Ying Han, M.D., Ph.D.

## INTRODUCTION

Difficulty with reading is common in individuals with traumatic brain injury (TBI). This fact is based upon their numerous reading-related symptoms, such as skipping lines, re-reading lines, reading slowly, and reduced reading efficiency (Ciuffreda and Tannen, 1995; Ciuffreda et al., 2001; Scheiman and Galloway, 2001; Zost, 2001, Han, Ciuffreda, and Kapoor, 2004; Ciuffreda et al., in press). Since a major contributory factor in reading ability is ocular motility, symptoms related to reading in individuals with TBI may not be surprising, as the majority (between 40 and 85%) manifest oculomotor abnormalities (Baker and Epstein, 1991; Suchoff et al., 1999; Ciuffreda et al., 2001). These include increased drift, saccadic intrusions, jerk nystagmus, and saccadic dysmetria (Ciuffreda and Tannen, 1995; Ciuffreda, 1994; Ciuffreda et al., 2001) (see Table 1). Such oculomotor anomalies will impact adversely upon both the sensory and motor-based aspects of the reading process (Ciuffreda and Tannen, 1995; Ciuffreda, 1994; Han, Ciuffreda, and Kapoor, 2004; Ciuffreda et al., in press). The presence of eye movement dysfunctions may also impede the rehabilitative process itself (Reding and Potes, 1988; Groswasser, Cohen, and Blankstein, 1990). Lastly, since reading is integral to many activities of daily living (ADL), it is logical that these reading-related oculomotor deficits would consequently decrease one's quality of life (Ciuffreda et al., in press).

Despite the importance of precise oculomotor control in reading, as well as the potential adverse consequences in the face of such dysfunction upon rehabilitation and quality of life aspects, few formal investigations in the area of oculomotor rehabilitation incorporating objective eye movement techniques have been performed in the TBI population (Ron et al., 1978; Ron, 1981; Ron, 1982; Gur and Ron, 1992; Ciuffreda et al., 1996, Kapoor, Ciuffreda, and Han, 2004). Nonetheless, oculomotor training paradigms have been proposed (Berne, 1990; Ron, 1981; Ron, 1982; Kapoor and Ciuffreda, 2002), which have resulted in the improvement of many parameters following ocular motor training in clinical (Berne, 1990) and laboratory objective (Ron, 1982) studies, respectively (see Table 2).

TABLE 1 Possible oculomotor anomalies associated with traumatic brain injury

| | |
|---|---|
| • Impaired overall oculomotor control<br>• Downbeat nystagmus<br>• Increased drift<br>• Saccadic intrusions<br>• Saccadic dysmetria<br>• Reduced gain of the vestibular-ocular reflex<br>• Reduced fusional vergence ranges<br>• Receded near point of convergence | • Divergence paralysis<br>• Spasm of the near reflex<br>• Multiple cranial nerve palsies/non-comitant strabismus<br>• Mechanical restriction of upgaze<br>• Fourth nerve palsy<br>• Strabismus<br>• Internuclear ophthalmoplegia |

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Reading is a complex task requiring precise linkage between the eye movements and the concurrent text processing. Normal reading consists of precise, rhythmical, and automatically-executed sequences of saccades interspersed with brief periods of fixation (Taylor, 1966; Robinson, 1977; Ciuffreda and Tannen, 1995; Ciuffreda et al., 1996; Ciuffreda et al., in press), thus producing a recording profile similar to a staircase when displayed as a function of time (Taylor, 1966; Ciuffreda and Tannen, 1995). There are high velocity saccades, typically being 1-3 degrees in amplitude and 30-60 msec in duration, which progressively shift the eyes horizontally from left-to-right across the line of print, with fixational pauses of 250 msec duration interspersed periodically to permit the processing and comprehension of the text, as well as positional programming for the subsequent saccade (Ciuffreda and Tannen, 1995). However, there are times when saccades may be regressive in nature, such that the eyes either glance back briefly to a previously fixated word for confirmation or shift to the beginning of the next line of text. In addition, other eye movement subsystems may be activated during reading, such as the vestibular system if the head is rotated, and the pursuit system if the material is smoothly shifted (Ciuffreda et al., 1996; Ciuffreda et al., 2001).

TABLE 2 Oculomotor improvements following vision therapy in individuals with traumatic brain injury

| Clinical Improvements | Laboratory Improvements |
|---|---|
| • Reduced exophoria at near<br>• Closer nearpoint of convergence<br>• Increased positive fusional range<br>• Improved King-Devick saccade test<br>• Concurrent elimination of diplopia and/or blur | • Faster rate of improvement for:<br>o Saccades 4.5X<br>o Optokinetic nystagmus 3.0X<br>o Pursuit 2.5X<br>• Higher level of improvement<br>• Some oculomotor subsystem transfer |

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Due to the increased occurrence of ocular motor deficits in the TBI population (Baker and Epstein, 1991; Suchoff et al., 1999; Suchoff et al., 2000; Ciuffreda et al., 2001; Zost 2001), we designed a systematic, computerized, objective oculomotor rehabilitative regimen. This was specifically tailored to individuals with TBI (Han, Ciuffreda, and Kapoor, 2004) who manifested signs and symptoms suggestive of an ocular motility-based component to their reading difficulty. In the present paper, selected aspects of our recent findings in the area are reported (Han, Ciuffreda, and Kapoor, 2004; Kapoor, Ciuffreda, and Han, 2004; Ciuffreda et al., in press). These investigations are the first to use objective oculomotor evaluative and training paradigms related to reading in the TBI population.

# METHODS

## Subjects

Subjects included nine adults (ages 30-70 years) with traumatic brain injury in reasonably stable general health. They were referred to the Raymond J. Greenwald Rehabilitation Center (RJGRC) at the SUNY/State College of Optometry from local hospitals and rehabilitation centers. Each subject manifested signs (e.g., saccadic dysmetria, increased drift) and symptoms (e.g., skipping lines, re-reading material) suggestive of an oculomotor-based component to their reading dysfunction. All had 20/30 or better corrected visual acuity. Subjects taking anti-psychotic, anti-seizure, or anti-anxiety medications with primary vision side effects were screened to insure the absence of either blurred vision or constant diplopia both prior to and during the period of study. All subjects presented with complete medical documentation at their first visit to the RJGRC. Each subject entered the study at least one year following their brain insult to ensure that any subsequent changes during training were not secondary to natural neurological recovery (Sbordone, Liter, and Pettler-Jennings, 1995).

This research was approved by the SUNY-Optometry's IRB Committee. It followed the tenets of the Declaration of Helsinki, with written informed consent having been obtained for each subject.

## Study Design

Prior to participating in the study, all subjects received a detailed vision examination in the RJGRC, which included monocular and binocular visual acuity at distance and near, refractive state at distance and near, binocular sensorimotor status at distance and near, accommodative and oculomotor control at near, color vision, and ocular health (Benjamin, 1998).

Then, each subject underwent objective eye movement testing, which included assessment of basic versional eye movements (fixation, saccades, and pursuit), simulated reading eye movements, and actual reading eye movements (Han, Ciuffreda, and Kapoor, 2004; Kapoor, Ciuffreda, and Han, 2004; Ciuffreda et al., in press). Following these assessments, each subject received computer-based, oculomotor training twice weekly for an 8-week period in a cross-over experimental design (Han, Ciuffreda, and Kapoor, 2004; Kapoor, Ciuffreda, and Han, 2004; Ciuffreda et al., in press). Both midway and at the conclusion of the 8-week training period, objective ocular motility testing was repeated. See Fig 1 for a flowchart showing the overall study design.

Individuals also completed a reading-related questionnaire indicating quantitatively their subjective assessment of reading ability before, midway, and after the training period (Han, Ciuffreda, and Kapoor, 2004). This rating-scale questionnaire consisted of five questions, including how long one can read comfortably, in which the rating ranged from 1-5, corresponding to 0 – 5 minutes, 5 - 10 minutes, 10 - 15 minutes, 15 - 30 minutes, and > 30 minutes, respectively. The other questions included how the person rated his/her overall reading comprehension, attention when reading in a quiet environment, and attention when reading in a noisy environment. These three questions were rated from 1 to 5, corresponding to poor, fair, good, very good, and excellent, respectively. Finally, each individual described his/her reading strategy, with four possible answers ranging from 1 to 4, corresponding to impulsive and inaccurate, deliberate but inaccurate, impulsive but accurate, and deliberate and accurate, respectively. Higher numbers on the reading-related questionnaire indicated better performance. Fractional values were permitted as responses to the questionnaire. This questionnaire was tested for both validity and reliability in a group of asymptomatic adults (n=20; ages 24-40 years).

## Apparatus: Objective Eye Movement Recording System

In all testing and training paradigms, the target consisted of a 0.5 degree, bright luminous square presented on an otherwise dark computer monitor positioned 40 centimeters from the subject along the midline. All paradigms were conducted under binocular viewing conditions with the appropriate refractive correction in place.

Objective assessment of basic binocular horizontal and vertical versional eye movements was performed with the OBER2 recording system (Koenig et al., 1997). The standard OBER2 sys-

FIGURE Flow chart showing experimental design of the study

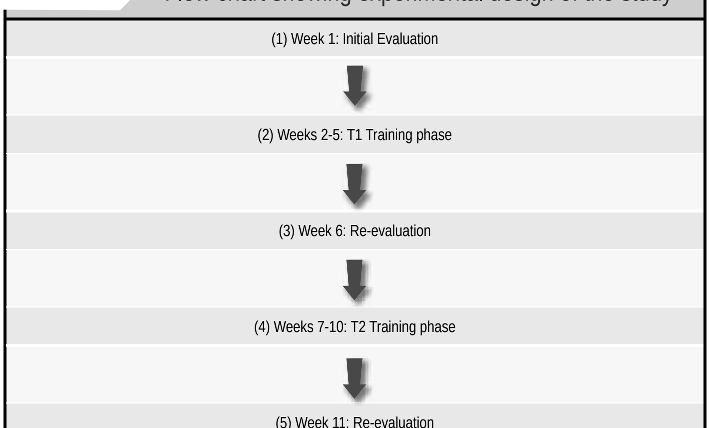


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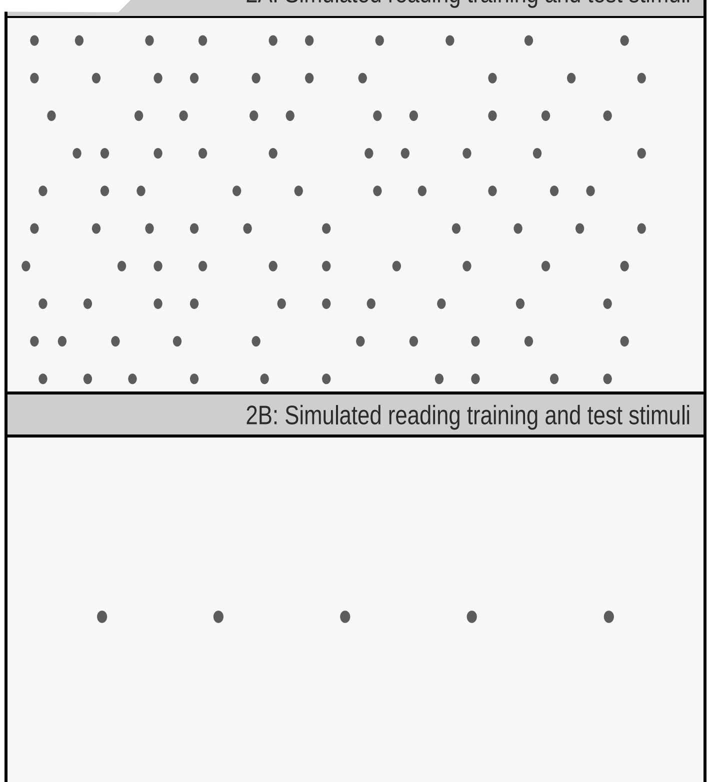
FIGURE 2A: Simulated reading training and test stimuli




A) Multiple line (ML), and B) Single line (SL). Reprinted with permission from Han Y., Ciuffreda K.J., Kapoor N., Reading-related oculomotor testing and training protocols for acquired brain injury in humans. *Brain Res Protoc.* 14: 4, Figure 3A and 3B, 2004.

tem consists of a goggle-mounted, infrared limbal reflection eye movement system. Auditory oculomotor feedback hardware related to horizontal and vertical eye position changes was custom designed and integrated into the standard OBER2 eye movement system. Basic versional ocular motility was tested, including fixation, predictable saccades, non-predictable saccades, and predictable pursuit, both horizontally and vertically (Ciuffreda and Tannen, 1995; Han, Ciuffreda, and Kapoor, 2004; Kapoor, Ciuffreda, and Han, 2004; Ciuffreda et al., in press).

In addition, simulated reading was tested using two reading patterns: a multiple-line (Figure 2A) and a single-line (Figure 2B) paradigm. The parameter used for analysis was the mean saccade frequency ratio. This was defined as the total number of saccades executed during the saccadic tracking task divided by the total number of target displacements. A ratio of 1.0 reflects a perfect response to the saccadic stimuli presented with one saccade executed per step target displacement (Han, Ciuffreda, and Kapoor, 2004; Kapoor, Ciuffreda, and Han, 2004). In both cases, subjects were instructed to follow the moving target accurately with a single saccade, as one would attempt to do during normal reading from word to word, to the positions shown in Figure 2. This paradigm permitted sequential, rhythmic reading oculomotor patterns to be trained and reinforced (Robinson, 1977; Fayos and Ciuffreda, 1998), in the absence of cognitive, perceptual, and language load, which occur during actual reading. Hence, both simulated reading paradigms are representative of pure oculomotor training tasks, which are related directly to the motor-based aspects of ocular motility involved in the reading process.

## Testing Apparatus: Visagraph Reading Eye Movement Measurements

Reading eye movements (horizontal position of both eyes) were recorded objectively using the commercially-available Visagraph II system (Instructional/Communications Technology, Inc., Huntington Station, New York) (Taylor, 1966; Fayos and Ciuffreda, 1998). This consisted of: (1) an infrared, limbal reflection, horizontal eye movement recording system, (2) hard copy of the test text at ten graded reading levels (grades 2 to high school), with ten 100-word, standardized paragraphs per level, (3) computer software for automated analysis of the eye movements and subsequent display of the grade-related oculomotor-based performance profiles for each basic reading eye movement parameters (Taylor, 1966), including reading rate, overall reading efficiency, comprehension, span of recognition, duration of fixation, number of progressive and regressive fixations, and number of saccades per line (Ciuffreda and Tannen, 1995), and (4) hard copy of the reading eye movements along with the tabulated grade-normative oculomotor performance levels. Subjects received one practice trial before actual testing, in which they read 2 adult level paragraphs, and the better performance was recorded. Analysis of the basic eye movement parameters described above was performed before, midway, and after training.

## Training Paradigms

Two training modes were used: normal visual feedback that occurs during eye movements (V) and visual plus external-based oculomotor auditory feedback (V+A). The only procedural difference in the training paradigms was the nature of the feedback. Auditory oculomotor feedback required the addition of an auditory tonal change related to the subject's eye position (Fayos and Ciuffreda, 1998; Han, Ciuffreda, and Kapoor, 2004). The auditory tone generator has a position-to-tone resolution of 0.25 degrees both horizontally and vertically. At the initial combined feedback training mode session, subjects received a verbal description of the tonal expectations for optimal ocular motor responses (Fayos and Ciuffreda, 1998; Han, Ciuffreda, and Kapoor, 2004). All subjects received 4 weeks of V+A as well as 4 weeks of V alone, which was randomly assigned using a cross-over experimental design (Hinkelmann and Kemphorne, 2005).

Eye movements were trained for a total of 36 minutes per training session, with rest periods being interspersed to minimize fatigue of the subject (Han, Ciuffreda, and Kapoor, 2004). The total duration for a session, including training and rest periods, was typically 60 minutes. The overall actual training time over the 8-week period was 576 minutes (9.6 hours), with the breakdown of ocular motor subsystems trained having been specified in an earlier paper (Han, Ciuffreda, and Kapoor, 2004).

TABLE 3 Reading rating-scale questionnaire results

| Question | Pre | T1 | T2 |
|---|---|---|---|
| 1. Length of time being able to read comfortably* | 1.33 +/-0.17 | 2.75 +/-0.25 | 3.67 +/-0.24 |
| 2. Ability to comprehend what was read* | 1.94 +/-0.34 | 3.00 +/-0.58 | 3.11 +/-0.26 |
| 3. Ability to attend when reading when in a quiet room* | 1.72 +/-0.15 | 2.63 +/-0.24 | 2.78 +/-0.28 |
| 4. Ability to attend when reading in a noisy room* | 1.11 +/-0.11 | 1.75 +/-0.25 | 1.89 +/-0.26 |
| 5. Categorize reading strategy* | 1.78 +/-0.36 | 2.33 +/-0.33 | 3.61 +/-0.23 |

Reading rating-scale questionnaire results. Data are presented for subjects with TBI (n=9). For questions 1-5, the mean response +/-1 SEM is noted for three conditions: before (pre), mid- (T1), and after (T2) completion of reading-related oculomotor rehabilitation. The statistical probability levels are indicated next to the question, with respect to the change in response from Pre to T2 using an asterisk notation: * = p<0.01.

## RESULTS

The group mean reading rating-scale questionnaire results are presented before, midway, and after training in Table 3. There were significant improvements in all 5 areas queried following the training. These included both subjective and timed improvements related to reading. The former was reflected by the greater than 50% increase in comprehension, while the latter was reflected by the 270% increase in reading duration with visual comfort.

With respect to objective eye movement findings, Table 4 presents the results for simulated reading eye movements before, midway, and after training. There were significant decreases in the saccade frequency ratio for each parameter both midway and following the training. Overall performance was better for the ML versus SL training paradigm. Thus, with training, the total num-

TABLE 4 Simulated reading mean saccade frequency ratio

| Simulated Reading Paradigm | Pre | T1 | T2 |
|---|---|---|---|
| Multiple Lines (ML) | 1.38 +/-0.100 | 1.11 +/-0.100 ** | 1.11 +/-0.100 ** |
| Single Line (SL) | 2.61 +/-0.200 | 1.95 +/-0.200 ** | 1.88 +/-0.200* |

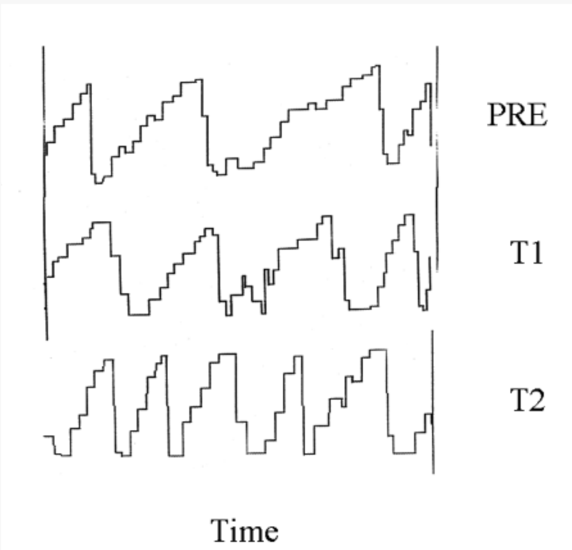
Data are presented as the mean saccade frequency ratio +/-1 SEM for subjects with TBI (n=9) for the three conditions: before (Pre), mid- (T1), and after (T2) reading-related oculomotor rehabilitation. Statistical probability levels in this table are noted next to the mean +/-1 SEM using an asterisk notation: * = p<0.01, ** = p<0.05, and *** = p<0.10. Asterisks to the right of the mean +/-1 SEM compare performance in each training phase to pre-training levels.

Data for Visagraph reading parameters for subjects with TBI (n=9)

| | Visagraph Parameter | Pre | T1 | T2 |
|---|---|---|---|---|
| Level 3 Paragraph | Words per minute | 196.9 +/-27.5 | 180.7 +/-15.5 | 196.3 +/-28.4 |
| | Grade level | 7.3 +/-1.5 | 6.9 +/-1.2 | 6.9 +/-1.6 |
| | Number of fixations per 100 words | 129.2 +/-15.8 | 128.1 +/-12.2 | 134.2 +/-17.9 |
| | Number of regressions per 100 words | 22.1 +/-5.6 | 21.8 +/-5.6 | 20.4 +/-4.8 |
| | Duration of fixation (in seconds) | 0.27 +/-0.01 | 0.27 +/-0.01 | 0.26 +/-0.01 |
| | Comprehension (% of questions answered correctly) | 82.2 +/-4.9 | 85.6 +/-4.4** | 84.4 +/-4.1 |

Data are presented for subjects with TBI (n=9) as mean values +/- 1 SEM for three conditions: before (Pre), mid- (T1), and after (T2) reading-related oculomotor rehabilitation. Statistical probability levels in this table are indicated by asterisk notation: * = p<0.01, ** = p<0.05, and *** = p<0.10. Asterisks to the right of the mean +/-1 SEM compare performance in each training phase to pre-training levels.

FIGURE Visagraph reading eye movement profiles for level 10 paragraphs for a 15-second interval in an individual with TBI.




Pre- (top), middle/T1 (center), and after /T2 (bottom) reading-related oculomotor rehabilitation. Up is leftward, and down is rightward.

ber of saccades executed reduced considerably, with the ML result essentially normalizing to a saccade frequency ratio value close to 1, which would represent a perfect performance.

With respect to other aspects of the objective eye movement findings, Table 5 presents the level 3 and level 10 Visagraph results. In contrast with both the group mean questionnaire and simulated reading results, in which consistent and large improvements were evident, this was not the case for the group mean Visagraph findings, especially for level 3. Few significant changes were found. However, when the individual data were assessed for level 10 reading, half of the subjects showed improvement in some of the parameters by up to 35%. One such example is presented in Figure 3, in which the reading eye movements are presented before, midway (T1), and after (T2) training. Both the number of progressive and regressive saccadic eye movements decreased during each phase of training, thus resulting in a reasonably normal staircase-like, oculomotor reading pattern. Reading rates were 137, 129, and 177 words per minute during each phase presented, respectively, thus resulting in a 30% increase in reading rate at the conclusion of training.

Due to the relatively small sample size and cross-over experimental design with its potential confounding training order effect, it was not deemed reasonable to assess statistically the effect of the addition of oculomotor auditory feedback on performance. However, based on informal analysis of the data, as well as subject comments, the combined feedback modes appeared to yield better objective and subjective results.

## DISCUSSION

The present results clearly demonstrate relatively large, consistent, and statistically significant improvements in all subjective aspects and many objective aspects of reading and related eye movement tracking in this adult TBI population. First, all individuals indicated that significant increases in their overall reading ability occurred. That is, they could read with better understanding, greater attention, and/or improved strategic approach. In addition, they could sustain reading longer with visual comfort. Second, the attentional-related aspects apparently spread to other vocational and avocational task domains, such as casual conversations and hobbies, i.e., activities of daily living (ADL). Third, there were marked objective improvements in saccadic tracking ability during the simulated reading task. Thus, there was improved motor control (Ciuffreda, 2002; Kapoor, Ciuffreda, and Han, 2004) related specifically to the saccadic eye movement system, which is the primary oculomotor system involved in reading (Taylor, 1966; Ciuffreda and Tannen, 1995). Fourth, with respect to the level 10 paragraphs, there was a significant reduction in the number of fixational pauses executed, which is a major limiting factor in reading speed (Ciuffreda and Tannen, 1995; Ciuffreda et al., 2001). Thus, some of the subjects read faster, with comprehension remaining high. The relatively minor training effect found for the level 3 reading appeared to reflect a saturation phenomenon, as the material was apparently too easy and was already being read well by the subjects. Fifth, improvements tended to be greater with the combined form of feedback, that is, when they could process their eye position errors and oculomotor rhythmicity through both the visual and auditory domains.

This is the first formal oculomotor rehabilitation testing and training protocol for reading remediation in the TBI population that incorporated both visual and auditory-based feedback modes. Based on our own observations, as well as comments of the subjects, they were able to use both the separate as well as the combined visual and auditory information regarding eye position and related oculomotor performance quite readily, and beneficially, with relatively rapid improvements evident. In fact, when the auditory feedback mode was added to the training phase, subjects were amused at the novelty of "hearing" their eyes move, and, furthermore, appreciated the instantaneous, direct, and easily interpretable information it provided to them regarding both their immediate and overall oculomotor performance. Moreover, when the auditory feedback was removed for the subset of individuals receiving visual feedback only in the second training phase, many of the subjects were distressed by the loss of this valuable feedback source. In future oculomotor rehabilitation paradigms, auditory feedback should be incorporated in conjunction with one's normal visual feedback to maximize potential training effectiveness.

The effects of training appeared to carry-over to other non-reading activities of daily living, for example, improved concentration during conversations, as mentioned earlier. Furthermore, it may have impact in another critical area, namely in facilitating other therapies that these individuals are receiving concurrently or will receive in the near future (Reding and Potes, 1988; Groswasser and Cohen, 1990). With improved reading skills, more precise oculomotor control, increased duration of reading comfort, and enhanced attentional abilities, other forms of therapy in which reading and related cognitive functions play an integral role, such as speech therapy and cognitive therapy, may be enhanced (Suchoff, et al., 2000). For example, if one can only sustain reading or general near vision tasks for a few minutes in a cognitive therapy session, this would not be sufficient to reap its full therapeutic benefit.

Home training was purposely not incorporated into the overall oculomotor training program. While it would be predicted to have enhanced the laboratory-based training effects, there would have been no control with respect to performing each aspect of the procedures properly, nor would timed aspects necessarily be accurately followed, as required for a formal scientific investigation. Hence, it would have confounded interpretation of the present experimental findings. However, in the standard clinic setting, home training should be prescribed for daily reinforcement, especially under these more naturalistic viewing conditions (Ciuffreda, 2002).

Due to the pervasiveness of the primary insult, acquired brain injury affects relatively large regions of the brain. In TBI, this pervasiveness is due to the complex coup-contrecoup nature of the traumatic event (Zost, 2001). Thus, precise and discrete cerebral localization effects of the training inferred from the oculomotor measures alone are limited (Kapoor, Ciuffreda, and Han, 2004). Despite localization difficulties, however, the brain's considerable neural plasticity and related motor learning can positively affect the reading-related versional oculomotor components of fixation, saccade, and pursuit aspects subsequent to the training. This notion was suggested and confirmed by the questionnaire outcome, as well as by anecdotal subject accounts. Future studies using high-resolution brain imaging techniques (e.g., functional MRI) in the TBI population before and after oculomotor training, as well as basic clinical lesion studies, will help to unravel further details of the underlying neural pathways.

No specific or purposeful attentional training was incorporated into the training program (Solan et al., 2003). While it may have been beneficial, it would have confounded interpretation of the basic experimental findings. One might speculate that the oculomotor training, by its inherent intense and continuous feedback nature, strongly but indirectly involved the training of visual attention, and perhaps even more general aspects of attention. For example, subjects sat very still and quietly during the 36 minutes of actual training per session, with their full attention directed to the specific oculomotor task at hand. Every effort was made by the subject to perform optimally during these extended periods of time, with multiple levels of performance-related feedback continuously present. Thus, the training of attention per se appeared to be both an integral part and a by-product of the oculomotor rehabilitation program. Future studies should include formal assessment of attention concurrent with the oculomotor rehabilitation program to gain insight into these complex interactions. The formal training of attention may even be considered for likely rehabilitative enhancement.

The current testing and training protocols have been easily and readily applied to a wide age range of adults with acquired brain injury. They may also be applied to children in the future, but with a more interesting test target such as a "smiling face", flickering and rotating star, randomly changing numbers, etc., to foster a high level of attention and visual engagement.

Many individuals with TBI have binocular vergence (i.e., tracking targets in-depth) dysfunction in addition to their versional (i.e., tracking targets laterally) dysfunction (Ciuffreda et al., 2001). Thus, specific vergence testing and training protocols need be developed and incorporated into the basic versional tracking and reading-related protocols, as required based on the clinical signs and symptoms manifested by the individual with TBI. In an earlier report, the framework for such a vergence training protocol has been proposed (Han, Ciuffreda, and Kapoor, 2004).

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Dr. Ying Han graduated with an M.D. in 1977 from The Fourth Army Medical University in Xin-an, China. In 1998, she received her Ph.D. from the Karolinska Institute in Stockholm, Sweden. Her primary research areas are proprioceptive interactions between eye and neck muscles, contrast sensitivity, and eye movement deficits associated with brain injury.

# The Diagnosis of Visual Unilateral Spatial Inattention

by Irwin B. Suchoff, O.D., D.O.S., F.A.A.O., F.C.O.V.D-R

## INTRODUCTION

Unilateral spatial inattention (USI), also known as "neglect", is arguably one of the most fascinating and challenging entities encountered by clinicians who provide care for individuals with acquired brain injury (ABI) (i.e. cerebral vascular accident (CVA) or traumatic brain injury (TBI)). It is perhaps one of the most under- or misdiagnosed sequelae of ABI. Failure to detect and treat USI can negatively affect both the individual's rehabilitation program and quality of life (Robertson and Halligan, 1999).

## AN OVERVIEW OF USI

### What is it, and why "USI" instead of "neglect"?

Driver and Vuilleumier (2001) have defined the condition as: ….a relatively common and disabling neurological disorder after unilateral brain damage. It is characterized by a lack of awareness for sensory events located toward the contralesional side of space (e.g., toward the left following a right lesion), together with a loss of orienting behaviors, exploratory search, and other actions that would normally be directed toward that side. Neglect patients often behave as if half of their world no longer exists.

In this definition, two concepts are critical in understanding the condition: a lack of awareness of sensory events on one side of space, and the individual's behavior indicating that half of the world no longer exists. In this respect, it has been recognized that the term "neglect" does not adequately describe the condition. "Neglect" signifies a purposeful act, such as "child neglect". This, however, does not accurately portray USI, which is characterized by the individual's unintentional lack of awareness and lack of attentional control over this lack of awareness. Other terms have been used such as: hemispatial imperception and unilateral visual inattention (Robertson and Halligan, 1999; Zost, 1995). It has been proposed that USI is more descriptive of the phenomenon and can lead to a greater appreciation of these major elements of the condition (Suchoff and Ciuffreda, 2004).

### When does it occur?

As stated in the above definition, USI can occur after any type of unilateral brain injury. However, it is said to be most common after CVA, particularly when the middle cerebral artery is involved (Gainotti, D'Erme, De Bonis, 1989).

### Where does it occur and what are the implications?

Lesions in several cortical and subcortical areas have been associated with USI. (Vallar and Perani, 1986). However, the majority of literature indicates that the neurological substrate of USI is parietal cortex, and more specifically the right posterior parietal (PP) cortex. (Driver and Vuilleumier, 2001; Gainotti, D'Erme, De Bonis, 1989; Stein, 1989).

Stein (1989) summarized the functions of the PP; it is the locus of one's body schema, which is the basis for visual guidance of movement and spatial orientation. He further identified these functions as occurring in personal space, peri-personal space and extra-personal space, respectively. He also proposed that ….hemispheric specialization in humans has led to these spatial functions being located mainly in the right hemisphere (Stein, 1989, p.589). Further, insult to the right PP can result in characteristic flawed behaviors in each of these spaces. Suchoff and Ciuffreda (2004) have specified these behaviors, some of which are presented in Tables 1-3.

### Clinically important characteristics of USI

USI behaviors cannot be adequately explained by basic motor or sensory impairments alone, although they might be present. {USI is something more than a basic motor or sensory impairment}. Consider an individual with ABI who has a lesion in the motor pathway that causes hemiplegia, but is unaware of the loss of control of limbs on the affected body side. See Table 1. Alternately, consider an individual with ABI with the same lesion causing hemiplegia, but who is aware of the limitations imposed by the hemiplegia. Both individuals have the same basic motor impairment. The key is the unawareness of the dysfunction (anosagnosia) exhibited by the first individual who has USI, indicating that the USI is something more than the basic motor impairment (Robertson and Halligan, 1999).

| TABLE 1 | USI behaviors in personal space |
|---|---|
| | • failure to recognize a severe hemiplegia<br>• failure to move a body part, but says he did<br>• instability of the body in space<br>• body schema unawareness |

| TABLE 2 | USI behaviors in peri-personal space |
|---|---|
| | • failure to apply make up to, or shave, one side of face, or comb one side of hair<br>• failure to copy or spontaneously draw one side of a picture<br>• unawareness of food on one side of the plate<br>• unawareness of objects on one side of furniture<br>• failure to place limb into shirt and/or trousers on one side when dressing |

| TABLE 3 | USI behaviors in extra-personal space |
|---|---|
| | • general unawareness of one side of the external world<br>• unresponsive to objects or people on one side of the external world<br>• inability to discern traffic or people on one side of the external world<br>• sudden "popping" up of people and/or objects on one side of the external world |

USI can occur in the presence or absence of a basic sensory or motor dysfunction. This is implied in the first general characteristic, above. In that example the first individual exhibits a form of USI personal space behavior (an unawareness of the hemiplegia); thus this person has USI in the presence of a basic motor dysfunction. However, consider another individual with ABI who demonstrates the same type of unawareness of the {hemiplegia}, but does not have the motor pathway lesion. This individual has USI in the absence of a basic motor dysfunction.

The individual with USI is prone to the extinction phenomenon. This phenomenon indicates the ability of an individual with ABI to identify a stimulus presented individually or simultaneously to the left side and right side of the body or space. However, the person with USI is unable to identify the stimulus presented on the contralesional side (i.e., person is unable to identify stimuli on the left side of visual space when there is a right-sided cerebral lesion) when both sides of space are simultaneously stimulated (Karnath, Himmelback, Kuker, 2003).

A common example is extinction testing for visual field defects; this type of testing is an essential probe for visual USI. In this instance, extinction is typically conducted as the second phase of confrontation testing. In the first phase, a single stimulus is presented first to the left and then to the right half of the visual field of the eye being tested; if there are no classical visual field defects, each stimulus is perceived. In the second phase, the left and right sides of that field are presented simultaneously with stimuli. In the case of USI, the individual does not perceive the stimulus on the USI (usually left) side (Gianutsos and Suchoff, 2002). The temporo-parietal junction of the cortex has been implicated as the neural substrate of visual extinction (Karnath, Himmelbach, Kuker; 2003).

## THE DIAGNOSIS OF VISUAL USI

The visual aspects of USI are manifested in extrapersonal and peripersonal spaces. Extra-personal space constitutes those areas beyond personal space that are greater than one's arm reach, while peripersonal space constitutes those areas beyond personal space within one's arms reach (Stein, 1989).

A prerequisite for maximal diagnosis of USI in these spaces (as with all individuals with ABI) are thorough ocular and visual evaluations. These should comprise assessments of: personal and family medical, ocular and visual histories, ocular health, visual acuities and refraction, ocular motilities, binocularity, accommodation, visual field testing, and basic areas of visual perception such as figure-ground and form perception (Suchoff, Kapoor, Waxman, et al, 1999). Dysfunctions in any of these areas can compromise findings in more advanced testing and must be considered.

Visual field testing is of prime importance in determining USI in both of these spaces. However, in order to understand the meaning of this type of testing, a discussion of some basic anatomical aspects of the visual system is necessary.

### Two major pathways of the visual system

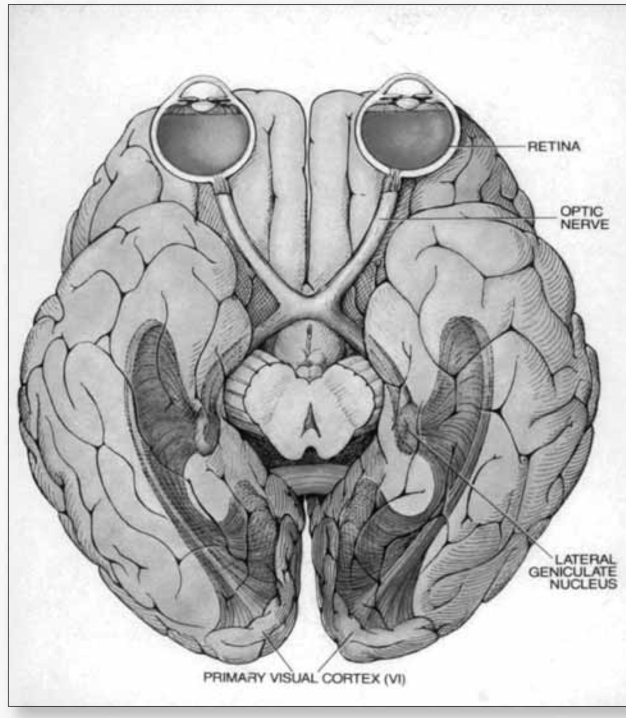
For the sake of this discussion, and at the risk of oversimplification, there are two predominant kinds of visual field considerations in ABI: homonymous hemianopia (HH) and USI. Each is the product of one of the two major pathways of the visual system.

### The primary visual pathway and visual field testing

The primary visual pathway proceeds from the retina to the occipital cortex and is considered as the basic visual sensory pathway. See Figure 1. At the Lateral Geniculate Nucleus (LGN), there is a separation of the visual fibers that originated at the retina into two divisions: 1) the Magnocellular (M) bundle, which is most sensitive to visual spatial and motion information, and 2) the Parvocellular (P) bundle that is most sensitive to visual detail and visual recognition. This separation continues throughout the courses of the primary and secondary pathways of the visual system (Kapoor and Ciuffreda, 2005).

The integrity of this primary visual pathway is assessed by conventional forms of visual field testing, i.e., kinetic or static perimetry. When the section of this pathway that is anterior to the optic chiasm is damaged, the result can be vision loss, ranging from discrete sections of the visual field to total blindness, depending on the location of the insult. Insult at the optic chiasm can result in a characteristic loss of the outer halves of the visual field of each eye. This is termed "bitemporal hemianopia". Depending on which optic tract is affected, an insult posterior to the optic chiasm characteristically results in the loss of corresponding quadrants of the visual field of each eye, e.g., right superior homonymous quadrantanopia; or the loss of corresponding halves of the visual field of each eye, e.g., left HH. Individuals with lesions in this pathway are aware of

FIGURE Primary Visual Pathway

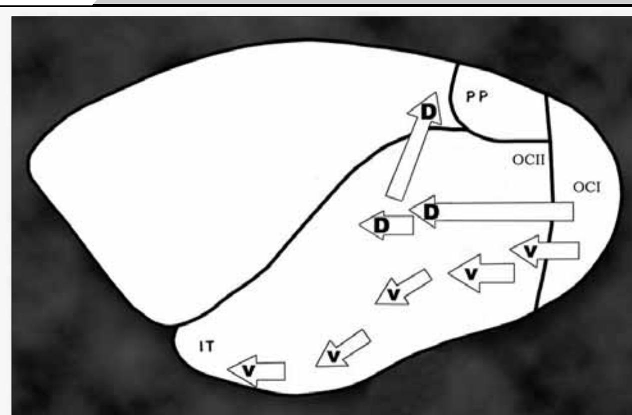



the loss of sensitivity in the affected field to varying degrees (Ciuffreda, Suchoff, Kapoor, et al, 2001).

### The secondary visual pathway (extended visual cortex) and visual field testing

The secondary visual pathway proceeds from the extrastriate occipital cortex in two streams: a ventral stream and a dorsal stream. The ventral stream is comprised of the P bundle, with the primary endpoint being the inferior temporal (IT) cortex of each side of the brain. The visual information conveyed is processed in IT primarily for visual recognition and identification of objects. The dorsal stream is comprised of the M bundle, with its primary endpoint being the parietal cortex on each side of the brain. See Figure 2. The visual information conveyed is processed in the parietal cortex primarily for motion and spatial vision (Suchoff, Gianutsos, Ciuffreda et al, 2000; Goodale and Miller, 2004; Kapoor

FIGURE Secondary Visual Pathway (Extended Visual Cortex)




OCI is the primary visual cortex
OCII is the deeper layer of the visual cortex
V is the ventral parvocellular stream
D is the dorsal magnocellular stream
IT is the inferior temporal brain
PP is the posterior parietal brain

and Ciuffreda, 2005).

Because its primary end is in the parietal cortex, the dorsal stream is the entity that is typically implicated in USI. However, insult to this stream will not be manifest in conventional perimetric testing; unlike the primary visual pathway, this dorsal stream is not a basic sensory pathway, but rather is a higher order perceptual entity of the visual system. Individuals with lesions in this pathway are unaware of the loss of sensitivity in the affected field to varying degrees. In terms of visual field integrity, insult to this dorsal stream is detected by extinction type testing, as described earlier (Suchoff and Ciuffreda, 2004).

It is possible that only the primary visual pathway, or only the dorsal stream part of the extended visual cortex pathway, can be compromised or that, as is particularly possible in TBI, both can be compromised. Three general scenarios then exist (Ferber and Karnath, 1999; Suchoff and Ciuffreda, 2004):

1. If only the primary pathway receives insult, there is a "pure" HH with awareness of the visual field defect on the part of the individual with ABI;
2. If only the dorsal stream receives insult, there is "pure" USI with no evidence of lateralized visual field defect;
3. If both entities are compromised, there will be USI with HH.

The second and third instances are the visual components of the earlier statement that USI can occur in the presence or absence of a basic (motor) or sensory dysfunction. The second instance is USI in the absence of a basic visual sensory dysfunction (hemianopia), while the third possibility is USI in the presence of a basic visual sensory dysfunction (hemianopia). The diagnostic challenge is to determine the individual's location in one of these three scenarios.

## A BASIC CLINICAL TESTING PROTOCOL FOR VISUAL USI

The following variables must be considered:

- the type and location of brain injury;
- the presence or absence of USI behaviors in personal and peri-personal spaces;
- the individual's level of awareness of these behaviors when present;
- visual field extinction testing results;
- conventional visual field testing results.

### Type and location of brain injury

Because insult to a number of cortical and sub-cortical areas has been associated with USI (Driver and Vuillemier, 2001; Vallar and Perani, 1986), all individuals with ABI should be suspect. However, individuals who have had a stroke, and all with right brain injury, are the most likely candidates for visual USI.

USI extra-personal behaviors and peri- personal behaviors

Specific questions should be directed toward the individual during the initial interview based on the behaviors delineated in Tables 2 and 3. Three questions that are particularly insightful are: Does it ever seem that one side of the world is missing? The individual with the "pure" HH generally will answer affirmatively, while the individual with the "pure" USI generally will deny. A second question is: Do you frequently bump into people and/or objects while you're walking? The "pure" HH person will answer affirmatively, and often state that it doesn't occur when he looks into that side of space. The "pure" USI person will disagree, often to the consternation of family members and/or rehabilitation personnel who are present (Suchoff and Ciuffreda, 2004). The same response categories apply to the question, Do you sometimes unintentionally miss eating food on one side of your plate?

Azouvi, Marchal, Samuel, et al (1996) devised a questionnaire that probes similar USI behaviors. The instrument is completed independently by the individual with ABI, the involved rehabilitation staff members, and/or relatives. In this manner, a comparison can be made between the individual's awareness of the behaviors with the observations of others.

### Visual field extinction testing

As alluded to earlier, the most basic form of determining visual extinction is conducted as a part of confrontation visual field testing. There are two parts to this testing: single field stimulation, and left and right fields' simultaneous stimulation. The latter is the test for extinction.

It has been suggested that the two-examiner method be used; one examiner presents the stimuli from behind the individual, while the other examiner faces the individual to monitor accurate central fixation. Thus, in the extinction testing, the examiner behind the individual simultaneously presents a stimulus to the right and left portions of the eye's visual field that is being tested (Gianutsos and Suchoff, 2002.)

### Visual field testing

Either kinetic or static computerized methods should be used. A basic screening program that tests beyond the central 30 degrees is preferable. This type of program can be accomplished in a time period that is reasonable for most individuals with ABI, and it tests a wider area of the field, which is of importance in determining USI.

## PROPOSED DIAGNOSTIC CATEGORIES OF VISUAL USI

As a result of the above considerations and testing, four diagnostic categories have been proposed (Suchoff and Ciuffreda, 2004). In all instances described below, the left visual fields are compromised.

1. HH without USI: Single field confrontation and perimetric testing indicate HH. The individual is aware of the field loss and does not demonstrate USI behaviors.
2. HH with USI: Confrontation single field testing and perimetric testing indicate HH. The individual is unaware of the field loss and exhibits fairly consistent USI behaviors.
3. Incomplete HH with USI: Confrontation single field testing does not indicate HH, but perimetric testing indicates a loss of sensitivity of the left, as compared to the right, side of visual space for each eye. Extinction testing shows a loss of sensitivity of the left field for each eye. The individual is unaware of the field loss and exhibits inconsistent USI behaviors.
4. USI without hemianopia: Confrontation single field testing and perimetric testing do not indicate HH. Extinction testing shows a loss of sensitivity of the left side of visual space for each eye. The individual is unaware of the field loss and exhibits consistent USI behaviors.

## SUPPLEMENTAL TESTING

### Computer based visual extinction testing

The individual being tested sits in front of a video display terminal, and the extinction testing can be conducted with or without a fixation point. In one program, the Single and Double Simultaneous Stimulus Test, the stimuli are an equal (=) sign and/or a minus (-) sign. These stimuli are presented individually to the extremes of either the left or right sides of the computer screen, or simultaneously to both sides. There are 45 discrete trials based on all possible presentations of the stimuli. These are presented in random order.

The individual being tested uses the keyboard to indicate his perception of the stimulus array for each presentation. The computer analysis determines the sensitivity of each field in terms of perceiving the stimulus or stimuli, and the accuracy of the perception (Gianutsos and Suchoff, 2002).

## The individual's perception of "straight ahead"

This type of investigation is based on some experimental evidence that a concomitant of visual USI is a shift in the individual's perception of veridical "straight ahead" toward the contralesional side of space. Karnath (1994) developed an opaque light bulb shaped cabin in which each of his subjects was seated. The examiner manipulated a laser pointer from left to right, or vice versa during trials in light and dark conditions. The subject was instructed to indicate when the laser spot was "straight ahead". The results were that Karnath's control group (ten individuals without brain injury and four individuals with left-brain injury) was on average within three degrees of true "straight ahead". However, his three subjects with right-brain parietal injury, who were deemed to have "pure" USI, located "straight ahead" an average of fifteen degrees to the right of true straight ahead. Research is presently ongoing to determine the effectiveness of this method in a larger sample (Kapoor, Ciuffreda, Harris, et al., 2001).

## Specific tests for USI in peri-personal space

There appears to be an implicit assumption that visual USI is an "all or nothing" phenomenon; that it is always present in both personal and peri- personal spaces. This is in spite of a lack of supporting evidence. Indeed Robertson and Halligan, (1999) claimed that it can be in the one space, but not the other. In this regard, it is important to present some testing that investigates USI in peri-personal space.

Basic tests in this space are paper and pencil tasks. In cancellation testing, an equal number of figures are printed across the left and right halves of a page. The individual being tested is asked to draw a line through ("cancel") all of the figures, or particular figures. In one line bisection task lines of varying lengths, but of equal lengths on the right and left sides of the paper, are presented. The individual is asked to mark the midpoint of each line. In these tasks, the individual with visual USI cancels more figures on the right side of the page, or biases the midpoint to the right side, respectively. The same type of behavior is manifest in copying or drawing objects; in the most florid type of USI, the left side of the object is completely absent.

The standardized Behavioral Inattention Test uses the above types of probes and provides other more challenging tasks, such as telephone dialing, picture scanning for details, setting time on a round faced clock and reading (Wilson, Cockburn, Halligan, 1986).

## SUMMARY

The diagnosis of visual USI requires an understanding of the overall taxonomy of the phenomenon along with knowledge of the primary and secondary visual pathways. The individual's behaviors must be considered, with conventional and extinction visual field testing being key factors in the diagnosis. A basic clinical protocol and supplemental testing have been presented, based on the literature and clinical experience.


### ABOUT THE AUTHOR

Dr. Suchoff was a member of the original faculty of the State University of New York, State College of Optometry (SUNY). He served that institution in didactic and clinical teaching roles, and as department chair, associate dean for the professional program and director of residency education. In 1992, Dr. Suchoff established the Head Trauma Vision Rehabilitation Unit, now the Raymond J Greenwald Rehabilitation Center, and served as its director. He has lectured on the visual consequences of acquired brain injury (ABI) at optometric continuing education meetings, to hospital rehabilitation unit staffs, and at optometric colleges for over 15 years. Dr. Suchoff has been lead or co-author of numerous articles on ABI in the optometric literature, chapters in several rehabilitative medicine texts, and was lead editor of the book, Visual and Vestibular Consequences of Acquired Brain Injury. He is editor of The Journal of Behavioral Optometry. Dr. Suchoff retired from SUNY in 2000, and holds the rank of Distinguished Service Professor Emeritus there. He now resides in Kennesaw, Georgia.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# Managing visual field defects following acquired brain injury

by Penelope S. Suter, O.D., F.C.O.V.D., F.A.B.D.A., F.N.O.R.A. and Neil Margolis, O.D., F.A.A.O., F.C.O.V.D.

## INTRODUCTION

Visual field defects are common sequelae of acquired brain injury. They vary from small isolated blind spots, or scotomata, to loss of vision in an entire hemifield, or from an entire eye. The visual consequences of visual field loss are not simply a matter of loss of visual information being gathered from the affected areas in the visual field, but include changes in the entire perceived structure of three dimensional space (e.g., Doricchi, et al., 2002), as well as shifts in the center of gravity (Rondot, 1992), which affect balance. Small scotomata can be extremely disruptive if they are near the area of central fixation, causing disruption of reading, and other activities of daily living that require fine visual discrimination, or orderly movement of the eye on a page. Ingrained patterns of eye movements with which one scans the world must often be entirely restructured following visual field loss, in order to effectively gather information from spaces that fall within the blind areas of the visual field (Ishiai, et al., 1987). Visual perceptual speed and span become critical, with more fixations being required to cover the relevant space and to gather information most expediently.

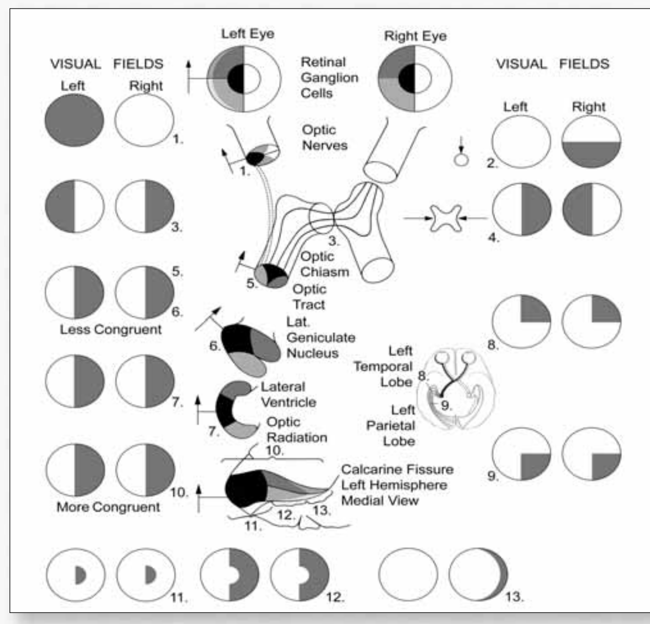
Management of visual field defects covers a broad spectrum of education, vision rehabilitation therapy, and optical aids. Unfortunately, most individuals with visual field defects are not referred for visual rehabilitation. Many individuals with significant visual field loss are told that they will simply adapt to the loss. These individuals may end up severely curtailing their activities because they do not feel safe in uncontrolled environments, or they may end up on the road driving without the benefit of either vision rehabilitation services or a certified driving evaluation. Members of the rehabilitation team should be aware that vision rehabilitation is a viable treatment option available for these individuals, which can significantly impact the quality of the overall rehabilitation outcome. These individuals should be referred to a vision rehabilitation specialist, such as an optometrist practicing neuro-optometric rehabilitation, for treatment (Appendix 1).

## NEUROANATOMY OF VISUAL FIELD DEFECTS

Visual field defects result from disruption of the primary retino-geniculate-occipital pathway. The neuroanatomy of visual field defects is quite orderly, allowing one to ascertain the general location of the lesion from the pattern of the defect (Figure 1). Unilateral visual field loss results from damage to the retina or optic nerve prior to the optic chiasm. At the optic chiasm, the ganglion cells from each eye partially decussate. The axons, which originate from the nasal retina, cross over to join the neurons from the temporal retina of the contralateral eye and then travel together to the lateral geniculate nucleus of the thalamus to synapse. From there, they travel posteriorly to the primary visual cortex in the occipital lobe. The functional result is that, beginning at the chiasm, the information from the right visual field for both eyes travels to the left side of the brain, and the visual information gathered from the left visual field for both eyes travels to the right side of the brain. Throughout their travels, the neurons remain organized in a retinotopic map of the visual field.

Visual field defects can usually be classified into one of several categories: (a) monocular which results from damage to the eye or optic nerve anterior to the optic chiasm, (b) binocular, (i.e. homonymous or heteronymous), sector, quadrant or hemifield loss, e.g. homonymous quadrantanopia or homonymous hemianopia, (c) concentric constriction of visual fields, or (d) altitudinal visual field loss. Homonymous quadrant or hemifield loss is common, and the congruency—i.e., the match between the defects measured from each eye--increases as one moves posteriorly along the visual pathway. Homonymous hemianopia is the most common visual field defect following brain injury (Zihl, 2000), and is the emphasis of this article. Concentric constriction of visual fields is a relatively common finding in brain injury and may result from selective magnocellular damage. Altitudinal visual field loss frequently follows bilateral anterior ischemic optic neuropathy.

FIGURE Visual field defects resulting from lesions in the retina-lateral geniculate nucleus-occipital cortex pathway




## TESTING FOR VISUAL FIELD DEFECTS

Testing for visual field defects following ABI must be tailored to the capabilities of the individual. Many individuals with ABI will be able to perform a standard projected or automated perimetry test on a threshold-based instrument if they have close monitoring, postural support as needed, and frequent breaks. For those unable to perform automated perimetry, visual field tests which are performed manually (e.g., the tangent screen) and permit a longer response time for the individual, can be performed. If a hemianopia is demonstrated, then an Amsler grid, a small graph paper with a central fixation dot that can be used to detect visual distortions within the macular area, should be used to accurately define how close to fixation the edge of the hemianopia extends. This information is critical in determining the sort of interventions that may be required for reading, writing, and various search tasks.

Confrontation visual field testing is a method for determining the most peripheral extent of the intact visual field and can be performed by most individuals, as the task is a simple one. The individual is to indicate when they first perceive a target being moved from behind their head into their sighted field. However, sensitivity of confrontation testing is poor, ranging in one study from 38% detection of abnormal visual field quadrants to 90% for detection of hemianopias (Shahinfar, 1995). Suchoff and Ciuffreda (2004) describe how confrontation testing is made more sensitive by using a two-person method so that there is reduced cuing for the target stimulus.

Functional testing does not restrict fixation but determines how efficiently different visual field quadrants are attended to. Large interactive electronic boards such as the Dynavision, Wayne Saccadic Fixator, or Acuvision board, as well as targets presented on computer screens (Gianutsos, 1991), can be used to evaluate visual fields in this functional manner.

Following ABI, visual field defects may occur with or without unilateral spatial inattention (USI), and the differential diagnosis must be made between these two entities. It is still the case that most general vision care practitioners, when seeing a deficit on a perimetric test, will assume that it is due to a visual field defect. In a visual field defect, the primary retina-LGN-occipital pathway is disrupted and there is a loss of visual input for "sight". USI is a complex disorder where the substrates for "sight" are intact, but the ability to attend to and therefore perceive the visual information is disrupted. On visual field testing, USI masquerades as a visual field defect. Differential diagnosis of USI vs. visual field defect is described by Suchoff and Ciuffreda (Suchoff and Ciuffreda, 2004). USI is much more dangerous to the individual with ABI than a visual field defect, as there is a general unawareness of the loss of information and an associated lack of compensation.

As with visual field defect, USI presents in different depths or densities. A person with severe USI may not demonstrate any evidence of sight in the unattended hemifield on automated perimetry or confrontation fields. On the other hand, the USI may be so mild that the individual only demonstrates deficits in visual perception on specialized testing or tasks that require simultaneous processing or divided attention.

Interestingly, individuals with hemianopia or other visual field deficits, without USI, sometimes take days or weeks to become aware of their deficit.This does not imply USI. Once aware, the individual without USI will remain aware of the visual field deficit.

## FUNCTIONAL IMPLICATIONS OF VISUAL FIELD DEFECTS

Monocular field defects can range from something as small as a macular hole, to loss of the entire eye in individuals with traumatic brain injuries. If the loss of vision occurs in the eye that has been the sighting dominant eye for driving, mobility and/or reading, the individual may express that, while they are able to see, they experience difficulty "thinking" while doing detailed vision tasks. The individual will often experience spatial disorientation. These individuals would benefit from rehabilitation techniques that assist them in re-establishing a stable egocentric reference.

Homonymous visual field deficits include sector defects, quadrantanopia, and hemianopia. Individuals with hemianopia may experience difficulty with running into or tripping over objects in the blind side. Efficient adaptive scanning patterns are not generally acquired without some direction and practice (Gassel and Williams, 1963). Walking through chaotic environments, such as busy public places, poses a safety risk for which the individual with a hemianopia must internalize habitual scanning patterns. A right hemianopia without several degrees of macular sparing results in severe disruption of reading, as the individual with the right hemianopia lacks the visual information required for pre-programming the eye movement to the next word. Left hemianopia is less disruptive but may cause the individual to lose their place as they move from line to line.

Individuals with homonymous hemianopia frequently experience egocentric visual midline shifts--i.e., a shift where the perceived straight ahead is shifted away from physical straight-ahead, causing a mismatch between perception and the physical reality (Barton and Black, 1998; Padula, 2000, Kapoor et al., 2001). These egocentric visual midline shifts cause veering, typically into the blind field, during mobility and driving. They also disrupt simple visual motor tasks such as eating or picking up a glass, demanding constant small corrective adjustments throughout the day. This can be fatiguing, and can leave these individuals feeling unsettled and unsure of themselves without knowing why. Both Padula (2000) and Valenti (1996) describe clinical methods for testing for egocentric visual midline shift.

Superior visual field loss only requires instruction on being aware of objects above eye level. On the other hand, individuals with homonymous inferior visual field loss may be severely impaired in mobility--particularly in environments with animals or children--as they cannot see obstacles near their feet. If the margin of the field deficit is close to the fixation point, they may also have difficulty with losing their place during reading. Individuals with concentric field loss will have similar difficulties.

## TREATMENT OF VISUAL FIELD DEFICITS WITH OR WITHOUT USI

It is important to share with the individual with hemianopia that the purpose of the lenses and vision rehabilitation therapy is to help them gain a more complete awareness of their surroundings in the most efficient manner. A clear differentiation between the prognoses for performance improvements versus actual visual field recovery should be made at the very outset before intervention is initiated. This is important to create realistic expectations and to avoid a sense of failure over time. Partial recovery of visual field defect, both through spontaneous recovery, and also resulting from vision rehabilitation therapy following spontaneous recovery, are common findings (e.g., Julkunen, et al., 2003). While it is not possible at this point to predict which individuals will show some recovery, the prognosis is better for those individuals who have a gradient of sensitivity at the edge of their visual field loss (Zihl, 1981). Most recovery of visual field is modest, averaging five to seven degrees in hemianopia, and found at the border of the sighted field (Zihl, 1981; Kerkhoff, 1992).

The purpose of using optical prism systems in glasses for hemianopia compensation is to shorten the time required to gain access to information on the side of the hemianopia and decrease the time attention is being diverted from the functional side. When prisms are used to compensate for field loss, the base is always placed in the direction of the field loss. Thus, images of objects in the periphery of the lost field are moved closer to the straight-ahead, or functional side. The use of prism requires therapy to retrain eye movements and to adjust to the altered perception of space.

The optical effect of wearing yoked prisms (prisms in front of both eyes with the base in the same direction) in glasses is that there is a shift of the visual image from the hemianopic field into the functional field. The advantage of full field yoked prism for hemianopia compensation is the instant access to the field enhancement with no special eye movements required. The disadvantage is the low amount of prism that can be realistically used to keep spatial distortion and the shift in perceived visual midline at an acceptable level.

Another compensatory prism system, the Peli system (Peli, 2001) uses relatively high power prism mounted on glasses above and below the line of sight. This produces the simultaneous perception of a central image created from the functional field and a peripheral image shifted over (by the narrow prism wedges) from the hemianopic side. The advantage of this system is that the use of higher-powered prisms creates wider field awareness while the design allows simultaneous access to both right and left visual field. The disadvantage is that the system is hard to adapt to and can cause visual confusion.

The Visual Field Awareness System™ (VFAS) (Gottlieb, 1998) uses a combination of eye movements into the hemianopic field side and relatively high amount of prism to increase field awareness. A round prism is inserted in a lens, placed just temporal to the pupil or at the temporal limbus on the affected side. The individual is taught to fixate into the prism to gain quick access to information on the hemianopic side. Therapy often uses the analogy of glancing into ones' side mirror when driving. The advantage of this system is relatively larger field awareness with minimal optical distortion. This system also reinforces scanning into the blind hemifield, which is critical to maintaining adequate spatial constructs in hemianopia. The disadvantage is confusion with the resulting double vision when viewing through the prism.

All these system options can be demonstrated to the individual using temporary, flexible press-on prisms that have inferior optics, but are inexpensive and versatile. Application of any of these optical aids requires vision rehabilitation therapy in order for one to achieve maximum benefit from them. For yoked prisms and the Peli prism systems, therapy generally incorporates activities that teach one to re-orient spatial judgments to the changes caused by the prism. Typically, this takes the form of visual-motor matching activities. With VFAS-like systems, the individual is also taught how to fixate quickly into the prism to gain awareness of objects in the hemianopic field, ignoring the double vision created. If something of interest is viewed in the prism, the individual must then turn their head toward the target to view it outside of the prism.

The authors have found the VFAS type of prism system to be the most popular system selected by individuals with hemianopia. Ultimately, the individual should achieve the ability to move forward while performing automatic fixations into the temporal prism, which is akin to adopting a radar mode of scanning where wide field awareness is gained without necessarily recognition. The repeated fixations into the temporal prism allow rapid access to object awareness in the hemianopic side with minimal loss of attention to the functional field.

Considerably more education is required in treating USI than in treating hemianopia. Individuals who have USI with hemianopia or who have marked USI without hemianopia do not typically appreciate the changes described above. They are not aware of the need to compensate for the affected side and make little attempt to look into peripheral prisms. The visual misperceptions associated with USI result in difficulty integrating the simultaneous peripheral and central visual information of the Peli-type prism. Full-field yoked prism glasses do manifest functional improvements in some individuals by creating a shift in the image space to better match the shifted perceived egocentric visual midline in USI. Also, the wearer does not have to do anything special to access the shifted images.

Egocentric visual midline shift tends to be in the opposite direction for individuals with USI, vs. those with visual field defect (Barton and Black, 1998; Doricchi et al., 2002)--toward the defect for individuals with hemianopia without USI, and away from the defect for individuals with USI. In both hemianopia and USI, re-structuring perceived visual space to create better visual and visual-motor matches between the perceived and actual location of objects in space is critical. This may require the use of lenses, prisms and/or rehabilitation therapy.

Some individuals achieve improved efficiency in compensating for their visual field loss using head turning and scanning techniques that require minimum demonstration by the rehabilitation professional. A small habitual head turn into the affected field may allow faster access to eye movements into that field, but head-turning as a method of scanning is inefficient and counterproductive (reviewed by Zihl, 2000). Compensatory oculomotor scanning training is a mainstay of treatment for both hemianopia and USI (Kerkhoff, et al., 1992; Zihl, 2000; Pambakian, et al., 2004). This training of oculomotor scanning has proven to be useful in both improvement of function (Gottlieb, 1998) and sometimes true expansion of residual visual field (Julkunen, et al. 2003). The individual with hemianopia without USI will be able to scan into the blind field on instruction. This training begins in predictable situations but must be generalized to non-predictable situations.

For visual demands where the margins are static and predictable such as paragraph reading, brightly-colored strips or a finger held against the text margin on the affected side serve to encourage more complete sentence scanning. Scanning playing card layouts, dotting specific letters in a paragraph, and calling out the first and last letter of each line are examples of therapies that can be used to improve page-scanning accuracy. Processing speed and span of recognition should be maximized along with the scanning training.

For non-predictive or dynamic situations such as walking or navigating a wheelchair, compensatory techniques are not as simple. Classically, the individual is taught to turn their head or scan towards the affected side. However, many individuals with USI have difficulty when told to move their eyes toward the affected visual field. Proprioceptive techniques, such as the Margolis Eye Throwing Technique (1996) where the individual is taught to "throw" their eyes as far as physically possible into the direction of the affected field can be helpful as they minimize reliance on "unattended" visual cues. Once the individual has mastered this technique and understands the concept of moving their eyes far into the affected field and scanning back, the individual can effectively engage in scanning activities in the therapy room, which must then be generalized to real world situations.

In addition to scanning, there are a variety of therapies designed to rehabilitate concepts of body image, directionality, visual spatial midline and visual spatial relations. These are necessary to reestablish matches between the perceived space and physical reality following significant visual field loss or USI.

**SUMMARY**

Visual field deficits can cause severe loss of function, spatial disorientation, and significant personal safety concerns following brain injury. Individuals with visual field deficits should be referred to a vision rehabilitation specialist for diagnosis and rehabilitation. Apparent visual field loss must be carefully differentiated from USI, as the appropriate education and therapeutic plan are dependent on this differential diagnosis. Rehabilitation for visual field loss includes use of lenses, prisms, and low vision devices, as well as vision rehabilitation therapy and compensatory strategies. These rehabilitative treatments are primarily aimed at reestablishing a stable visual spatial construct, which matches the physical world. Individuals with significant visual field deficits who participate in vision rehabilitation have the best prognosis for achieving personal independence and safety goals.

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### APPENDIX 1
### Resources for accessing post-brain-injury vision rehabilitation professionals

The following websites provide geographic listings of potential visual rehabilitation practitioners.

Neuro-Optometric Rehabilitation Association, International
www.nora.org

College of Optometrists in Vision Development
www.covd.org

Optometric Extension Program
www.oep.prg

Adaptive driving evaluations and training can be obtained from members of The Association for Driver Rehabilitation Specialists
www.driver-ed.org

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# Vision rehabilitation following acquired brain injury: a case series

by Carl G. Hillier, O.D., F.C.O.V.D.

## INTRODUCTION

Sudden onset acquired brain injury (ABI) causes an immediate change in one's ability to function in the world. This disruption manifests itself in a multitude of ways. Since such a large part of the human brain is involved with processing information visually, guiding movement visually, and integrating vision with other sensory modalities, ABI very frequently disrupts vision function (Kapoor and Ciuffreda, 2002; Suchoff, et al., 1999; Suter, 2004; Zost, 2001).

Since the visual experience is so dominant for most individuals, ABI can interfere significantly with one's ability to reconnect with habitual life activities, as well as with the multiple rehabilitative interventions. Fortunately, immediate interventions are now available to individuals with ABI, thereby enabling them to re-acquire visual abilities in processing, movement, and sensory motor integration.

This paper presents three case reports demonstrating how neuro-optometric rehabilitation in a hospital setting can provide immediate improvement, not only in the ability to perform and improve with collateral rehabilitative interventions, but also in one's quality of life.

## Case #1: Sudden-onset double vision

AB, a 45-year-old Hispanic-American male, initially presented for optometric evaluation on January 07, 2005 due to reports of constant diplopia following a stroke. The stroke occurred on December 28, 2004 along the vertebral artery, resulting in disruption of the neuro-motor control of the right superior oblique muscle and a consequent right hypertropia. This right hypertropia caused AB to present with constant vertical diplopia, which made it difficult for him to establish a consistent and reliable connection with the physical, social and therapeutic environment that surrounded him.

AB had the option of either having his environment being double or to have one eye patched and having a 2-dimensional world to negotiate. Due to the vertical diplopia, directing fine-motor movement or visually guiding ambulation was significantly impaired during the in-hospital therapeutic process. Both options, neither of which provided an optimal therapeutic interface for physical, speech, cognitive, and occupation therapy, would have been very challenging since AB was accustomed to a 3-D world.

The initial findings for AB are shown in Table 1. AB presented with best-corrected visual acuities of 20/20 in each eye, unremarkable ocular health, and pronounced 8-10 prism diopter right hypertropia in straight-ahead (i.e., primary) gaze. The initial findings also demonstrated that the ocular misalignment increases on left gaze, which is characteristic for a right fourth cranial nerve lesion.

TABLE 1 Initial Findings for AB

| | | |
|---|---|---|
| Aided visual acuity | | Right eye: 20/20 |
| | | Left eye: 20/20 |
| Far Ocular Misalignment | Primary Gaze | 10 prism diopters right hypertropia |
| Near Ocular Misalignment | Right Gaze | 3 prism diopters right hypertropia |
| | Primary Gaze | 8-10 prism diopters right hypertropia |
| | Left Gaze | 12 prism diopters right hypertropia |
| Ocular health status | | Within normal limits in each eye |

The initial treatment involved the application of an 8 prism diopters base-down prism to the right spectacle lens. It was cut to size and placed on the posterior surface to minimize a negative cosmetic result. AB experienced immediate resolution of diplopia in all fields of gaze. During the subsequent week, AB participated in vision rehabilitation to develop and stabilize fusional vergence ranges. The techniques required AB to make step and ramp fusional vergence using reflexive and cognitive control over his ocular alignment. After one week, the 8 diopters prism was reduced to 6 prism diopters base-down. He continued to engage in visual fusion therapy for the next two weeks. A re-assessment at that time revealed the ability to fuse with only 2 prism diopters base-down before the right eye. After one more week of fusional vergence therapy, AB was able to discontinue the use of the prism altogether. The final findings for AB, shown in Table 2, revealed the reduction of the ocular misalignment.

TABLE 2 Final Findings for AB

| | | |
|---|---|---|
| Aided visual acuity | | Right eye: 20/20 |
| | | Left eye: 20/20 |
| Far Ocular Misalignment | Primary Gaze | 3 prism diopters right hypertropia |
| Near Ocular Misalignment | Right Gaze | 0 prism diopters right hypertropia |
| | Primary Gaze | 2-3 prism diopters right hypertropia |
| | Left Gaze | 4 prism diopters right hypertropia |
| Ocular health status | | Within normal limits in each eye |

During his four-week period of fusional vergence therapy, AB was able to participate in all in-hospital rehabilitative activities under binocular viewing conditions with no reports of diplopia. This reduction in diplopia under binocular viewing conditions provided increased confidence and comfort for AB when participating in other in-hospital rehabilitative sessions.

In addition, it significantly improved his emotional outlook regarding his recovery.

## Case #2: Diplopia, photophobia, vestibular dysfunction, and a left visual field defect

Traumatic brain injury (TBI) can result in a complicated array of visual dysfunctions. This is especially true when the trauma is induced externally and where the injury occupies several different regions of the brain (Hellerstein and Freed, 1994; Hellerstein, Freed, and Maples, 1995; Suchoff, Ciuffreda, and Kapoor, 2001; Suter, 2004).

JH is a 30-year-old male who was hit in the head with a baseball bat and experienced several subsequent vision problems. The injury, which occurred on August 28, 1998, affected his right posterior parietal lobe and part of his right occipital lobe. JH participated in several different therapeutic modalities, including speech and language therapy, physical therapy, and occupational therapy. These various therapies were programmed to help him overcome the linguistic, vestibular, and integrative impairments, which became evident subsequent to the TBI.

Occupational therapy referred JH to neuro-optometry on April 22, 1999 for a more thorough vision evaluation due to his symptoms of double vision, photophobia, balance disorder, and left visual field defect (i.e., homonymous hemianopia). The initial optometric findings (see Table 3) revealed best-corrected visual acuity of 20/30 in the right eye and 20/20 in the left eye, a 25-30 prism diopter right exotropia with restricted upgaze in the right eye only, a left hemianopia in each eye, and bilaterally sluggish pupillary responses.

The anatomical midline of the body, or physical egocenter, is the normal reference point for movement and sensory input. Neurological impairments can result in a mismatch in the coherence or alignment of anatomical, perceptual and movement systems of the body, such that the perceived egocenter does not match the true physical egocenter (Kapoor et al., 2001; Padula and Argyris, 1996). This shift of the reference point for movement and sensory information away from the anatomical midline is often referred to as a visual midline shift syndrome and may cause a person to be unsteady or off-balance when sitting, standing and walking (Padula and Argyris, 1996; Suter, 2004).

At the initial evaluation, in addition to the findings presented in Table 3, JH revealed a left visual perceptual midline shift whereby he perceives objects that are in front of him and on his left to be centrally located. So he has a visual perceptual midline shift whereby he misjudges the spatial location of objects in his visual field to be up and to the right when in fact they are level with his eyes.

TABLE 3 Initial Findings for JH

| | | |
|---|---|---|
| Aided visual acuity | | Right eye: 20/30 |
| | | Left eye: 20/20 |
| Far Ocular Misalignment | Primary Gaze | 25 prism diopters right exotropia |
| Near Ocular Misalignment | Primary Gaze | 25-30 prism diopters right exotropia |
| Extraocular motility | | Right eye: restricted on upgaze only, with the maximum extent being 20 degrees |
| | | Lef eye: full, but jerky and unsteady on upgaze |
| Ocular health status | | Within normal limits in each eye, except for a left hemianopia in each eye and sluggish pupillary responses for each eye |

A combination of optometric interventions were recommended for JH. These included the application of a temporary, compensatory fusional prism to immediately eliminate the diplopia related to the right exotropia, tinted lenses to reduce the symptoms of photophobia, a field-awareness prism to increase his awareness of the affected left visual field, and yoked prisms to help compensate for the shift in JH's visual perception of his midline. The yoked prism application was designed to increase his confidence while ambulating with minimal balance problems. The combination of all four therapeutic interventions was designed to improve JH's ability to function visually with reduced diplopia and light sensitivity, as well as increased awareness of his affected visual field.

Upon wearing the tinted, yoked prism spectacles, in conjunction with the temporary fusional prism and a field-awareness prism on the left lens, there was an immediate resolution of the diplopia and photophobia for JH. In addition, he began to exhibit a normal visual perceptual midline with objects in 3-dimensional space and felt much more confident and stable while ambulating through unfamiliar environments. He was no longer leaning to one side or bumping into objects within his visual field, from which he used to sustain injuries. After adapting to the glasses and being trained with the use of the field-awareness prism, JH improved in his ability to function visually, which impacted his performance positively, with respect to his other rehabilitative therapies, as well as his basic activities of daily living.

## Case #3: Right visual field defect

A visual consequence of occipital stroke is that it typically leaves an individual missing half of their visual field in each eye. This type of visual field loss is called a homonymous hemianopia. Homonymous hemianopia is common among individuals who suffer a stroke (Padula and Argyris, 1996; Peli, 2000; Vargas-Martin and Peli, 2002; Suter, 2004; Zost, 2001). Isolation of a stroke to the occipital lobe does not typically result in concurrent cognitive impairments. An occipital lobe lesion results typically in a loss of the homonymous visual field contralateral to the side of the lesion. Therefore, a stroke in the left occipital lobe typically results in right homonymous hemianopia, where neither eye sees to the right of wherever the eye is aimed. The following is a case report about an individual who suffered a stroke to the left occipital area in March of 2003, resulting in a right homonymous hemianopia.

JM, a 65-year-old male, was seen initially by a neuro-ophthalmologist who diagnosed the left occipital stroke resulting in right homonymous hemianopia. He was subsequently referred in July of 2003 for a neuro-optometric evaluation and subsequent vision rehabilitation for his impaired functional visual abilities in the right visual field for each eye.

Upon examination in July of 2003, JM's findings (see Table 4) revealed 20/20 eyesight at far and near through lenses, which compensated for myopia, astigmatism and presbyopia. His binocular status was revealed 5 prism diopters of exophoria in the distance and 10 prism diopters of exophoria at near. Extraocular motility was full but jerky in each eye. Although JM had the ability to fuse, he also demonstrated difficulty with sustaining fusional vergence. Ocular health was unremarkable, aside from the right homonymous hemianopia. Lastly, a brief screening using a standardized reading test showed that he was fluent in

TABLE 4 Initial findings for JM

| | | |
|---|---|---|
| Aided visual acuity | | Right eye: 20/20 |
| | | Left eye: 20/20 |
| Far Ocular Misalignment | Primary Gaze | 5 prism diopters exophoria |
| Near Ocular Misalignment | Primary Gaze | 10 prism diopters exophoria |
| Extraocular motility | | Right eye: full, but jerky |
| | | Left eye: full, but jerky |
| Ocular health status | | Within normal limits in each eye, except for a right hemianopia in each eye |

his ability to read.

Given these initial findings, it was determined that JM would benefit from the use of a field-awareness prism, scanning therapy, and fusional vergence therapy using home-based and in-office vision rehabilitative techniques (Kapoor and Ciuffreda, 2002). This optometric treatment began in October of 2003 and was completed in April 2004 after 22 in-office sessions.

During this period of in-office visual rehabilitation and home-based activities, JM had been wearing a field-awareness prism placed above his right eye's line of sight along the top one third of his spectacle lenses. This was in the form of a 20 prism diopter base-out prism that enabled information from his right (otherwise blind) visual field to be moved over into his left seeing field in the superior field of his right eye. This provided an opportunity for him to become aware of novel stimuli in his right visual field (experienced by him by seeing this information in his upper left visual field of the right eye) with a reduced reaction time.

JM reported how grateful he was that the neuro-ophthalmologist recommended neuro-optometric vision rehabilitative therapy. His wife has also noticed that he is safer and much more capable of ambulating through space especially in public settings or unfamiliar physical surroundings. Although the homonymous hemianopia is organically unchanged from his initial findings, his functional ability to contend with the homonymous hemianopia has significantly improved, resulting in a consequent and significant improvement in his quality of life.

This case history is typical of those who enter into neuro-optometric vision rehabilitative therapy and who engage in the optometric treatment for homonymous hemianopia to overcome the functional deficits secondary to visual field loss. The use of a field-awareness prism, in-office visual rehabilitative techniques to increase the individual's awareness of the affected visual field, and a variety of compensatory and supportive therapies frequently results in improved functional abilities for individuals with homonymous hemianopia (Peli, 2000; Vargas-Martin and Peli, 2002; Padula and Argyris 1996; Kapoor and Ciuffreda, 2002; Suter, 2004; Zost, 2001).

## CONCLUSIONS

The above three cases illustrate how neuro-optometric vision rehabilitation in conjunction with optical aids such as fusional prisms, yoked prisms, field-awareness prisms, and tints may benefit the visual capability, as well as accuracy and steadiness during ambulation, for an individuals with stroke or TBI. This improved visual function makes it easier for the person to carry out basic activities of daily living. In addition, with increased visual function, the improvement in one's ability to perform various visually-guided tasks is also evident in other types of rehabilitative therapies, including physical, vestibular, speech and language, cognitive, and occupational therapies.

## ABOUT THE AUTHOR

In 1977, Dr. Hillier earned a Bachelor of Arts degree in psychology from the University of California, San Diego. Dr. Hillier earned a Bachelor of Science in Visual Science, and his Doctor of Optometry degree from Pacific University in 1982. He was appointed a Lieutenant in the United States Navy and served as an optometrist from 1982 through 1985, where he directed the orthoptics clinic. He is a Fellow in the College of Optometrists in Vision Development. Dr. Hillier founded the Vision Rehabilitation Clinic at the San Diego Rehabilitation Institute at the Alvarado Medical Center. He is also an adjunct clinical professor for the Southern California College of Optometry and lectures nationally and internationally on topics related to brain injury, sports vision training and developmental vision dysfunctions.

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