Clinical Oculomotor Training in Traumatic Brain Injury

Kenneth J. Ciuffreda, OD, PhD, FAAO, FCOVD-A;
Diana P. Ludlam, BS, COVT; Neera Kapoor, OD, MS, FAAO
SUNY/State College of Optometry

ABSTRACT

Individuals with traumatic brain injury present with a constellation of oculomotor dysfunctions and correlated symptoms. Simple and effective clinical oculomotor-based training procedures will be presented with respect to the versional, vergence, and accommodative systems, and their interactions. These therapeutic procedures can also be applied as needed to individuals with either low vision, neurological dysfunctions, or general visual skills cases manifesting similar oculomotor deficits.

Keywords: accommodation, eye movements, oculomotor learning, optometric vision therapy, traumatic brain injury, vergence, version, visual system plasticity

Background

Individuals with traumatic brain injury (TBI) manifest a constellation of oculomotor deficits of both the versional and vergence systems, in conjunction with accommodation and its interactions.[1-9] For example, in a recent retrospective analysis of ambulatory outpatients with mild TBI and related vision symptoms, over 90% were found to have one or more oculomotor dysfunctions, including nystagmus and/or other abnormalities of version, vergence, accommodation, and eye alignment.[5-7] Related symptoms included difficulty tracking objects, impaired visual scanning, and slowed reading (Table 1). Related signs included a receded near point of convergence, saccadic dysmetria, and poor fixational ability including the presence of nystagmus[5,6] (Table 2). Using a range of optometric vision therapy

Table 1: Oculomotor and Visual Symptoms in TBI
- Avoidance of near tasks
- Oculomotor-based reading difficulties
- Eye tracking problems
- Eye focusing problems
- Eyestrain
- Diplopia
- Dizziness
- Vertigo
- Vision-derived nausea
- Increased sensitivity to visual motion
- Visual inattention and distractibility
- Short-term visual memory loss
- Difficulty judging distances (relative and absolute)
- Difficulty with global scanning
- Difficulty with personal grooming, especially involving the face
- Inability to interact/cope visually in a complex social situation (e.g., minimal eye contact)
- Inability to tolerate complex visual environments (e.g., grocery store aisles and highly-patterned floors)

Table 2: Oculomotor Signs in TBI
- Reduced amplitude of accommodation
- Increased lag of accommodation
- Reduced relative accommodation
- Slowed accommodative facility
- Uncorrected hyperopia/ astigmatism (due to inability to compensate accommodatively)
- Receded near point of convergence
- Restricted relative convergence (BO) at far and near
- Restricted overall fusional vergence ranges at far and near
- Abnormal Developmental Eye Movement test (DEM) results
- Low grade-level equivalent performance on the Visagraph II
- Impaired versional ocular motility

Correspondence regarding this article can be emailed to kciuffreda@sunyopt.edu or sent to: Kenneth J. Ciuffreda, O.D., Ph.D. SUNY/State College of Optometry Department of Vision Sciences 33 West 42nd Street New York, NY 10036 Telephone: (212) 938-5765. *All statements are the author's personal opinion and may not reflect the opinions of the College of Optometrists in Vision Development, Optometry & Vision Development or any institution or organization to which the author may be affiliated. Permission to use reprints of this article must be obtained from the editor. Copyright 2009 College of Optometrists in Vision Development. OVD is indexed in the Directory of Open Access Journals. Online access is available at http://www.covd.org.*

Ciuffreda KJ, Ludlam DP, Kapoor N. Clinical oculomotor training in traumatic brain injury. Optom Vis Dev 2009;40(1):16-23.

approaches, many of the deficits were remediated in the vast majority of these patients (~90%).[5-7]

Only recently have formal oculomotor training protocols specifically addressing the patient with mild TBI been established.[10-13] However, these were developed for use in conjunction with computers only. In the present paper, specific protocols will be presented in detail, but with an emphasis on simplicity and being primarily non-computer-based in nature, although the global concepts are the same, and thus may be applied in either situation. These include the versional (e.g., saccades, pursuit), vergence (e.g., fusional vergence), and accommodative (e.g., accommodative vergence) systems, and their interactions, with these simple therapy paradigms being readily conducted in the contemporary optometric clinical and hospital environment, and as therapy conducted at home. Since these patients exhibit rapid fatigue and an inability to sustain attention, an effective strategy is to begin training at the highest level possible rather than to follow a rote "lock-step" and rigid "easy to hard" task level process irrespective of their performance level.

The procedures described will be primarily for the individual with mild TBI.[2,6,7] However, they can be modified appropriately for those with moderate to severe TBI who manifest a correlated reduction in basic oculomotor abilities and potential remediation expectations. For example, in a severely-impaired TBI patient, the options are markedly reduced, as will be described later. Furthermore, the proposed training protocols are sufficiently general to be used for patients manifesting similar oculomotor deficits in conjunction with either low vision or neurological dysfunction[14] (Table 3), as well as general oculomotor skill deficits.[15]

Protocols for Oculomotor Training (see Table 4)

I. Versional Training

Fixation

Patients with TBI frequently manifest an array of fixational abnormalities, including increased drift, saccadic intrusions, and nystagmus.[4,6,10-13,16] These deficits need to be remediated, as they may interact adversely with other types/aspects of versional and vergence eye movements, and with accommodation, and thus give the misperception that these other systems per se are worse than they really are.

Fixation should first be trained at 40 cm along the midline, or in the null position in cases of nystagmus. Then other directions (e.g., 10 degrees up or 10 degrees right) and distances (e.g., 6 meters) can be gradually introduced as performance improves. Depending upon the severity of the fixational dysfunction, the clinician could also use differently-sized targets. For example, once the patient can fixate well on a large target such as a finger tip, then the target size can be decreased to approach the size of a penlight or pencil tip. Visual and/or cognitive distracters can also be introduced to increase the difficulty level. Training should be performed with continuous verbal feedback from the therapist or doctor, as this serves to heighten the patient's visual attention.[17] If oculomotor auditory feedback is available,[10,17] it provides an excellent source of external feedback related to dynamic performance. And, concurrently you may wish to utilize arm pointing to the target to assist in providing kinesthetic information.[17] Fixational training can be

Table 3: Some Neurological Conditions Amenable to Oculomotor Training

- Cerebral palsy
- Multiple sclerosis
- Mysthenia gravis
- Brain tumor
- Autism
- Mild retardation
- Microcephalia
- Parkinson's disease
- Complex regional pain syndrome

Table 4: Simplified Protocol for Oculomotor Training

Saccades

- First and last word
- First and last letter
- DEM as a training tool
- Narrow and widely-spaced targets on a blackboard

Pursuit

- Predictable
- Non-predictable
- Non-predictable with added cognitive load

Vergence

- Loose prism (BO & BI)
- Brock string
- Vectographs
- Computer orthoptics
- Stereoscope (BOP/BIM)
- Marsden ball
- Add head rotation to stimulate vergence/vestibular interactions

performed monocularly, as well as binocularly in conjunction with a red filter over one eye to control for the presence of unwanted binocular suppression. Repeated 5-10 second therapy intervals may be used to minimize fatigue and maximize attention.

In some cases, the patient may have difficulty executing full ocular excursions during the training of fixation in eccentric gaze (up to 40 degrees). This may be due to the presence of pain and/or sensitivity in the surrounding region of the orbit which received the initial insult. In such cases, slow and repeated displacement of the fixational target into the affected region is useful to increase the ocular range. This could also be performed with a mirror in two ways: 1) with the head fixed and the eyes tracking their image in the mirror, or 2) with the mirror fixed on the midline with the patient rotating their head very slowly with large excursions either laterally or vertically. While success with this approach has been found in non-paretic cases, we have had some degree of success even in the more extreme scenario of paresis, presumably due to residual oculomotor plasticity.[18]

Saccades

Patients with TBI frequently manifest saccadic abnormalities, such as hypometria (undershooting), at times hypermetria (overshooting), and an excessive number of saccades during reading.[11-13, 18] These oculomotor deficits must be remediated, as they will interfere with visual scanning, reading, ambulation, and even adversely impact other forms of rehabilitative therapy (e.g., cognitive therapy) involving visual search paradigms.[19-21]

Saccadic training has many aspects that can be gradually introduced and modified as needed. The specified procedures can be performed at distance and near. Target size may be varied, as described earlier for fixation. It should incorporate predictable as well as non-predictable target motions. The amplitudes should also vary, but since most naturally-occurring saccades (without head movement) are 15 degrees or less in amplitude,[22] the emphasis should be on small to medium-sized saccades (as used in reading across a line of print).[18] It should be noted that 40 degree saccades are rarely made in our daily activities, especially in the absence of head movement.[23,24] However, one may wish to train coordinated eye and head movements to large target, step displacements as the training progresses, in conjunction with vestibular aspects as described later. The directions should vary with purposeful testing in the horizontal, vertical, and oblique meridians. Moreover, training should involve horizontal movement above, at, and below eye level into the reading region. One can use either verbal commands or a metronome to guide temporal aspects of saccadic tracking. Use of oculomotor auditory feedback,[10,11,13,17] if available, can provide another important source of information related to saccadic accuracy and the subsequent period of sustained gaze before the next saccade. If the saccadic movement is perfectly accurate, one would hear a single and abrupt tonal change that remains constant during the brief inter-saccadic fixational period.[18] Concurrently having the patient point to the target may be assistive in nature especially during the early phases of training.

We have found one technique to be especially helpful, with direct relevance to the reading process. The patient holds a page containing several rows of sentences within a few paragraphs. In the first phase, they saccade to the first word in line one, call it out, maintain fixation for a 3-5 seconds, and then saccade to the last word in line one, again call it out, and then maintain the short period of fixation using either verbal commands or a metronome. The process progressively continues down the lines of text. As progress takes place, the rate of change is increased. And, with further progress, the patient repeats the above, but now saccading to the first and last letter of each line, which increases the level of difficulty. This technique in essence trains both saccades and fixation in a more naturalistic context similar to reading. You can also add visual and/or auditory distractors to increase the level of difficulty.

Pursuit

Patients with TBI manifest several pursuit abnormalities, in particular reduced gain (i.e., the smooth eye velocity is slower than the target velocity) with a resultant increased frequency of saccades to "catch-up" and foveate the target as it continues to move. Clinically, this is visualized as "jerky" or "saccadic" pursuit. In addition, if jerk nystagmus is present as determined during the fixational testing, the pursuit response will be grossly asymmetric. It will appear to be smooth when the target direction and slow-phase of the nystagmus are in the same direction, and jerky when they are in opposing directions, due to the summation of the pursuit signal, the eye movement signal and their related interactive neuromuscular dynamics.[18] Pursuit plays a subtle role in the reading process. For example, in situations in which a book is smoothly displaced, perhaps while reading in a moving bus or subway, a pursuit response will be elicited.[18] Pursuit may also comprise a subcomponent of the fixational process.[18]

Pursuit therapy can follow those aspects articulated in the section on saccadic training. For example, the target can initially be large, and as performance improves, it can be made progressively smaller. Basically, the target should be smoothly displaced at 5 degrees/sec or so over an amplitude of +/- 5 to 10 degrees centered about the midline at a distance of 40cm (this is considerably slower and smaller in amplitude than frequently performed). The goal for the clinician is to visualize and rate the overall quality of the movement with respect to smoothness and frequency of saccades. If one were to move the target too rapidly, this would result primarily in a saccadic tracking response, rather than a smooth pursuit per se. However, as performance improves, one may wish to use such an upper level velocity endpoint criterion in the assessment of pursuit and, as with saccadic training, the target directions can be horizontal, vertical, and oblique. Furthermore, one may use a hierarchical strategy progressing from a predictable stimulus to a non-predictable stimulus, and finally concluding with a non-predictable stimulus having a cognitive load added (e.g., spelling one's last name while tracking).

Vestibular

Lastly, there is vestibular therapy. A low-gain vestibular-ocular reflex (VOR) is frequently evident in TBI patients with concurrent and extremely troublesome oscillopsia.[18] The VOR is critical to reading. If it is abnormal and any degree of head movement occurs, illusory movement of the text and the surrounding environment will be apparent. Its importance becomes evident when one considers the VOR characteristics: its gain is 1.0 under most conditions, such that there is exact compensation by the eyes as the head is rotated, and furthermore, this compensation is nearly instantaneous with its very short 16 msec latency.[18] Thus, any neurological perturbation has immediate adverse visual consequences if the VOR system is not intact.

Training of the VOR starts in the distance with binocular viewing of an accommodative target just above one's visual acuity threshold. This is done so that if any oscillopsia or blur becomes evident, target visibility will immediately be adversely affected. Hence, this information can serve as an excellent source of visual feedback related to oculomotor performance. Head rotation amplitude should be about 10-20 degrees, starting very slowly (<0.5Hz) perhaps following the beat of a metronome. Over time as performance improves, target frequency can be gradually increased to a moderate level (e.g., 1Hz or a bit higher), and the amplitude might also be increased. Once the VOR at distance begins to exhibit consistent improvement, the target can be moved to closer distances, such as 1 meter. Gradually, since the VOR gain continually increases as target distance decreases, the target should be displaced inward to approximately 20 cm.[18] This can be readily performed using a Brock string. Training over a wide range of distances, with the resultant dynamic changes in vestibular/vergence interactions, is essential for eventual reflexive oculomotor responsivity in the absence of the sensations of oscillopsia, nausea, dizziness, or vertigo.[18]

II. Vergence Therapy

Patients with TBI manifest a range of vergence abnormalities, with the most prominent being convergence insufficiency,[5-7] which is often noted as a receded near point of convergence.[15] However, other deficits may include slowed dynamic responses[18,25,26] and restricted relative ranges.[5,6] Since there are dynamic changes in the vergence angle with each fixational shift, vergence plays a major role in reading,[14,18,27] especially during the large return-sweep saccade. Vergence is also critical during one's activities of daily living, as objects of interest at different distance are bifixated in our highly complex, three-dimensional visual world. And, as discussed earlier, the VOR/vergence interplay is essential for visual perceptual stability.

A conservative, dual-mode, model-based[28] approach to vergence therapy may be used that incorporates both ramp and step stimuli. Essentially, one would start with a slowly-moving ramp (~0.5 degrees/sec), gradually increasing the speed to approximately 2-5 degrees/sec. As performance improves, rapid step changes can be introduced, at first small in magnitude (~2 prism diopters), and gradually increasing to 6-10 prism diopters (pd), both base-out and base-in. One can start with a large fusable target and gradually progress to a very small and more difficult fusable target that also provides an appropriate accommodative stimulus (e.g., a high contrast pattern or Snellen letter). This can first be performed along the midline and then in eccentric gaze (~10-20 degrees). However, if one finds that the ramp training is not very challenging and initial performance is good, then this phase may be bypassed in favor of the more challenging step stimuli. Fusional training employing step inputs is probably the more important of the two, as it reflects the reflex fusional response to diplopic imagery that a patient may frequently encounter. Reflex fusional training can be implemented in the horizontal, vertical, and oblique meridians dependent upon the directional aspect of the diplopia and related symptomatology. Some suggested in-office and home therapy procedures include the following:

1. Loose prism: 6pd base-out and base-in over either eye in free space for approximately one minute for each condition at near. As one reads or gazes at targets in space, the prism is periodically removed and then added back every 5 seconds to stimulate reflex fusion. The prism is gradually increased to 10pd for added difficulty. The goal for this, as well as other forms of step training, is to develop reflexively rapid and accurate fusion that can be sustained without effort.
2. Polarized vectograms: base-out and base-in ramp and step stimuli with a gradual increase in range and magnitude, with concurrent SILO (i.e., small-in, large-out) perceptual sensation.
3. Computer orthoptics; as per #1 and 2 above.
4. Brock string (3-bead variety): as per #1 and 2 above. Performed first along the midline, then eccentrically, and then with a vertical aspect as performance improves to the "effortless" reflexive level (while utilizing the general principles of motor learning).[29]
5. Hand-held stereoscope: BOP/BIM (i.e., base out prism with plus lenses/ base in prism with minus lenses) stimuli.
6. Marsden ball: using circular, lateral, and fore/aft movements to add a dynamic, free space aspect.

III. Accommodative Training

Patients with TBI manifest a constellation of accommodative abnormalities, with the most prominent being accommodative insufficiency[5,6] as reflected by reduced accommodative amplitudes. In addition, they may exhibit slowed and inaccurate accommodative responsivity.[5,6,2] Accommodative deficits may result in symptoms including intermittent blur, inability to sustain focus, and reading difficulty due to the transient blur.[5,6,15] These deficits can occur in isolation, or more typically in conjunction with the vergence system (i.e., variation in vergence accommodation per the CAC ratio).[30]

As suggested for the vergence system, a conservative, dual-mode, model-based[31] approach to accommodative training may be used (i.e., ramp and step stimuli). Essentially, one would start with a slowly-moving ramp (~0.5D/sec), gradually increasing to a speed of approximately 2-5 D/sec. As performance improves, rapid step changes can be introduced, at first small in magnitude (~0.5D) and gradually increasing to 2-2.5D, both monocularly and binocularly. Aspects related to target size and gaze angle can be varied, as suggested earlier for vergence. And, if one finds that the ramp training is not very challenging, and initial performance is good, then this phase may be bypassed in favor of the more difficult step stimuli. The same is true with respect to viewing condition: one may skip ahead to binocular viewing if monocular responsivity is not adversely affected. And as is true for the vergence system, the accommodative step input is probably the more important of the two, as it reflects the typical accommodative response to objects located at discrete distances in our complex, three-dimensional visual world.

There are two main types of training:

1. Lens flipper accommodative rock: Starting with lower powered lenses (e.g., +1.0/-1.5D) and high contrast, threshold visual acuity letters at 40 cm along the midline, and gradually increasing to +/- 2.5D if possible; overall lower lens values would be used in 30-40 year-old adult patients. The task is to introduce the lenses in a rapid step-wise manner, obtain and sustain focus for 5 sec, and then repeat in an alternating manner between the plus and minus lenses.
2. Hart chart accommodative rock: the shift in accommodative stimulus levels is performed with two targets in free space rather than with lenses as #1 above. The procedure is conducted as #1 above.

In addition, one may use a Marsden ball having differently-sized targets attached to act as a dynamic accommodative stimulus; the different targets are focused upon and identified as the ball moves in a quasi-predictable manner. Lens flippers could also be introduced to increase the level of difficulty under this real-life dynamic scenario.

IV. Interventions for the Patient with Severe TBI

The procedures discussed previously can be altered and modified to begin interventions bedside and sometimes even when the patient is considered semi-comatose. Before beginning any of the following procedures, one must carefully review the medical chart and speak to the attending physician(s)/therapists/nursing staff describing the proposed plan of treatment and asking them for their observations of any attempt at various visual behaviors by the patient.

One can begin these activities by gently turning the patient's head from side to side and naming the side and items of interest on that side as the head is rotated. This is performed after clearing the implementation of such movement with the other doctors and therapists (especially if there have been any recent surgical interventions, areas of concern from axonal shearing of the brain, brainstem, etc.).

Basic therapy to stimulate eye movements can be conducted even while the eyes are closed by touching the temples, nasal canthi, or upper lid and lower lid sequentially, accompanied by verbal instructions to "look toward your right, left, up, and down". Although the patient may not exhibit any obvious signs of consciousness, it is quite common for them to report memories of the procedures and related conversations that occurred in the patient's presence while they were still considered comatose or semi-comatose (more commonly referred to as a minimally conscious state or "waking coma").

Later, the eyelids can be gently opened by the doctor/therapist/trained family member and the eye stimulated by a penlight. The penlight should be moved discretely at first, stimulating right, left, up, and down gaze. This should be accompanied by verbal instruction and affirmation of any attempts to initiate movement in the requested direction. Often this activity will lead to rudimentary pupillary responses that can be evaluated. At this point, it is important to know the patient's pre-trauma vision history, especially with respect to their spectacle and/or contact lens use to insure that the appropriate spectacle or contact lens correction is worn.

Ask the therapist/caregiver/family member to address the patient directly when requesting the execution of eye movements in specific directions such as "aim your eyes to the right", or "aim your eyes to the sound of my voice, I'm over here on your right side". This can be altered in many ways by instructing the patient to attempt to look at their toes or the television, or by holding their hand and asking them to aim their eyes at the hand you are holding while naming and verbally labeling the hand right or left.

When the patient is stable enough, ask the nursing staff/physical therapist to place the patient in a wheelchair and continue this type of stimulation. A running description of the environment indicating the direction of an object of interest should be ongoing while moving the patient slowly through the hall and around the room (space allowing). A visit to the nursing station calling the staff present by name and indicating where they are accompanied by a request to "look at Nancy" is stimulating. Request the staff to address the patient by name and ask the patient to "look at me, I'm over here on your left side". The therapist/family member should also touch the appropriate side of the patient during these activities.

If possible, attend the daily staff meeting during discussion of the patient. This will allow you to interact with the other doctors and therapists who are providing rehabilitation services. Simply suggesting how physical therapists and occupational therapists can begin to integrate visual instructions and reinforcement when implementing their activities can enhance the visual intervention therapeutic process. This leads to a better understanding of the inter-disciplinary work between the various professions invested in providing a patient with the best outcome possible.

Once the patient has begun to respond by attempting to open their eyes and trying to follow instructions as to where to look, a more sophisticated type of vision therapy can begin. Adding vergence activities is easily accomplished by using photos of faces of family members (referring to them by relationship and name) viewed at a distance of between 10 to 16 inches. You can then use the face of a therapist or family member present in the room at a distance of 10 to 15 feet (referring to that person by name and function) as a distant viewing object. Instruct the patient to look between the far and near faces while calling out the names, as well as pointing at each face. This serves to facilitate the process by providing multi-sensory information and integration (i.e., vision, audition, motor, and proprioception), as well as training the accommodative mechanism. At this time, rudimentary pursuit activities can also be introduced using a light stimulus or object (cell phone, large watch, etc.) and employing auditory clueing simultaneously. A clicker, soft bell, or similar type of stimulus to move along with the visual target is helpful, as well as verbally indicating the direction in which the target is being displaced. For instance: "The cell phone is moving to your right, and the little bell that you can hear is moving along with the cell phone. Now they are moving back to your left. You are doing very well. Try to keep your eyes on the cell phone. Great!"

At this point, fixating, and then touching objects in different fields of view, can be introduced. It is often beneficial to use the same object for this work as was employed for the target in the pursuit process. Move the target in predictable paths, e.g., left to right asking the patient to point to the target. If this is too difficult, allow them to touch the target they are attempting to watch and even facilitate the arm movement by assisting with that motion. Of course, this presupposes the patient's ability to make such arm movements. In addition, this activity can be used to address visual field defects. In severe TBI, it is generally very difficult to obtain information regarding the patency of the visual field. Thus, investigating the patient's response during this activity may afford information regarding the visual field that will be useful later in the rehabilitation process.

All of the above activities can be modified in increasing difficulty and discrimination as the patient's improvement allows.

Discussion

This paper provides protocols for oculomotor training in patients with TBI, with an emphasis on mild TBI. However, for the most severe cases (e.g., semi-comatose), suggestions to initiate directed eye movements and eye contact in the context of simple naturalistic environments, such as at bedside or in the more general hospital setting, have been provided. And, in those with moderate TBI, some compromise training position can be developed based upon the patient's overall condition and realistic expectations.

While the emphasis has been on simple in-office, home, and/or hospital-based training procedures using a range of hand-held test targets, the same concepts have been applied to computer-based oculomotor training in mild TBI.[1-9] In addition, we are presently in the process of developing a simple and versatile commercially-available computer software program discussed in the present paper and in detail elsewhere.[10-13] This would serve as an adjunct to that described in the present paper for use in all possible settings.

Oculomotor training has been demonstrated to result in large and relatively rapid improvements in both the clinic and laboratory environments.[25] However, it is important to recall that the ultimate purpose of such training is to improve one's activities of daily living (ADL). Thus, training can be incorporated into one's daily routines for additional reinforcement. For example, as a passenger in a car, one can practice vergence by systematically converging on the dashboard, then diverging to an oncoming car, and repeating this several times during the drive to provide a dynamic training situation. And, in the case of a child, one can use a large spoon to perform pursuit and casually rotating the spoon to obtain either an upright magnified or inverted minified attentional getting image, during the course of helping a parent bake a cake. Numerous other such examples abound. Thus, the vision therapy can be incorporated into the typical daily situation with their heightened attentional aspects, as well as in the more structured office or laboratory setting.

Although oculomotor training alone can be extremely beneficial, use of a near vision spectacle prescription frequently serves as an important adjunct both during and following the completion of successful vision therapy. For one of us (DPL), the typical near addition for a non-presbyope is +1.25D. This lens power results[32] in a "binocular balance" between accommodation and vergence with the planes of both systems being conjugate with the target plane (i.e., simultaneous retinal conjugacy of both accommodation and vergence). This notion of moderately-low plus powered lenses for near is consistent with oculomotor models of myopia progression.[33]

Lastly, what mechanisms may be involved in oculomotor-based vision therapy? First, and most prominent, there is oculomotor learning (which is a more specific aspect of motor learning).[29] Essentially, motor learning takes place with relatively few systematic repetitions (up to 300 repetitions in TBI and only 70 repetitions in visually-normal individuals).[34] Second, visual attention and, perhaps even more global general attention are part and parcel of the training process, with its most important aspect being a continuous visual feedback system.[17] And, third, in those with either quadrantanopic or hemianopic visual field defects (~20%[35]) the oculomotor practice (especially predictable saccadic tracking across the midline) may involve recalibration/remapping of visual space, including egocentric localization, to make it more consonant with veridical visual space.[36-38]

Conclusion

A set of clinical procedures and guidelines has been presented for oculomotor training in individuals with mild TBI, including versional, vergence, and accommodative subsystems. When used in conjunction with other related information in the literature (e.g., Kapoor and Ciuffreda[3]), the optometric clinician should have the basic armamentarium to provide comprehensive remediation for a range of oculomotor dysfunctions in those with TBI. When the therapy procedures noted in this paper are utilized as recommended above, this should enhance neuroplasticity, functionality, and quality of life for the patient.[39,40]

References

1. Suchoff IB, Kapoor N, Waxman R, Ference W. The occurrence of visual and ocular conditions in an acquired brain-injured patient sample. Journal of the American Optometric Association 1999: 70:301-308.
2. Suchoff IB, Ciuffreda KJ, Kapoor N (eds). Visual and vestibular consequences of acquired brain injury. Santa Ana, CA: Optometric Extension Program Foundation Press, 2001.
3. Kapoor N, Ciuffreda KJ. Vision disturbances following traumatic brain injury. Current Treatment Options in Neurology 2002: 4: 271-280.
4. Kapoor N, Ciuffreda KJ. Vision problems. In Silver JM, McAllister TW, and Yudofsky SC (eds) Textbook of traumatic brain injury, First edition. American Psychiatric Publishing, Inc., Washington, DC. 2005: 405-417.
5. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. Optometry 2007: 78(4): 155-61.
6. Ciuffreda KJ, Kapoor N. Oculomotor dysfunctions, their remediation, and reading-related problems in mild traumatic brain injury. Journal of Behavioral Optometry 2007: 18 (3): 72-77.
7. Ciuffreda KJ, Rutner D, Kapoor N, Suchoff IB, Craig S, Han ME. Vision therapy for oculomotor dysfunctions in acquired brain injury: a retrospective analysis. Optometry 2008: 79(1):18-22.
8. Craig SB, Kapoor N, Ciuffreda KJ, Suchoff IB, Han ME, Rutner D. Profile of selected aspects of visually-symptomatic individuals with acquired brain injury: a retrospective study. Journal of Behavioral Optometry 2008: 19 (1): 7-10.
9. Kapoor N, Ciuffreda KJ. Vision deficits following acquired brain injury. In Cristian A (ed) Medical management of the adult with a neurological disability. Demos Medical Publishing, New York, NY. in press for 2009.
10. Han Y, Ciuffreda KJ, Kapoor N. Reading-related oculomotor testing and training protocols for acquired brain injury in humans. Brain Research Brain Research Protocols 2004: 14: 1-12.
11. Kapoor N, Ciuffreda KJ, Han Y. Oculomotor rehabilitation in acquired brain injury: a case series. Arch Phys Med Rehabil 2004: 85(10): 1667-1678.
12. Ciuffreda KJ, Kapoor N, Han Y. Reading-related ocular motor deficits in traumatic brain injury, Brain Injury Professional 2005: 2 (3): 16-20.
13. Ciuffreda KJ, Han Y, Kapoor N, Ficarra AP. Oculomotor rehabilitation for reading in acquired brain injury. NeuroRehabil 2006: 21(1): 9-21.
14. Ciuffreda KJ. Reading eye movements in patients with oculomotor disturbances. In Ygge J and Lennerstrand G (eds) Eye Movements and Reading, Pergamon Press, New York NY. 1994: 163-188.
15. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders, 2nd Edition. Lippincott, Philadelphia PA. 2002.
16. Ciuffreda KJ, Suchoff IB, Marrone M, Ahmann E. Oculomotor rehabilitation in traumatic brain-injured patients. Journal of Behavioral Optometry 1996: 7: 31-38.
17. Ciuffreda KJ, Tannen B, Rutner D. Multi-sensory feedback therapy for oculomotor dysfunction. In Hung GK and Ciuffreda KJ (eds) Models of the Visual System. Kluwer/Plenum, New York NY. 2002: 741-769.
18. Ciuffreda KJ, Tannen B. Eye movement basics for the clinician. Mosby Yearbook, St. Louis MO. 1995.
19. Grosswasser Z, Cohen M, Blankstein E. Polytrauma associated with traumatic brain injury: incidence, nature, and impact on rehabilitation outcome. Brain Injury 1990: 4: 161-166.
20. Gianutsos R, Suchoff IB. Neuropsychological consequences of mild brain injury and optometric implications. In Suchoff IB, Ciuffreda KJ, and Kapoor N (eds) Visual and vestibular consequences of acquired brain injury. Optometric Extension Program Foundation Press, Santa Ana CA. 2001: 48-55.
21. Reding MJ, Potes E. Rehabilitation outcome following initial unilateral hemispheric stroke: life table analysis approach. Stroke 1988: 19: 1354-1358.
22. Bahill AT, Adler D, Stark L. Most naturally-occurring human saccades have magnitudes of 15 degrees or less. Invest Ophthal 1975: 14: 468-472.
23. Han Y, Ciuffreda KJ, Selenow A, Bauer E, Ali SR, Spencer W. Static aspects of eye and head movements during reading in a simulated computer-based environment with single-vision and progressive lenses. Invest Ophthalmol Vis Sci 2003: 44: 145-153.
24. Han Y, Ciuffreda KJ, Selenow A, Ali SR. Dynamic interactions of eye and head movements when reading with single-vision and progressive lenses in a simulated computer-based environment. Invest Ophthalmol Vis Sci 2003: 44: 1534-1545.
25. Ciuffreda, K.J., Han, Y., Kapoor, N., & Suchoff, I.B. (2001). Oculomotor consequences of acquired brain injury. In Suchoff IB, Ciuffreda KJ, and Kapoor N (eds) Visual and vestibular consequences of acquired brain injury. Optometric Extension Program Foundation Press, Santa Ana CA. 2001: 77-88.
26. Scheiman M, Gallaway M. (2001). Vision therapy to treat binocular vision disorders after acquired brain injury: factors affecting prognosis. In Suchoff IB, Ciuffreda KJ, and Kapoor N (eds) Visual and vestibular consequences of acquired brain injury. Optometric Extension Program Foundation Press, Santa Ana CA. 2001: 89-113.
27. Taylor EA. The fundamental reading skill. Springfield, IL 1966 Charles C.Thomas.
28. Hung GK, Semmlow JL, Ciuffreda KJ. A dual-mode dynamic model of the vergence eye movement system. IEEE Trans Biomedical Engineering 1986: BME-233: 1021-1028.
29. Ciuffreda KJ. The efficacy of and scientific basic for optometric vision therapy in non-strabismic accommodative and vergence disorders. Optometry 2002: 73:735-762.
30. Hung GK, Ciuffreda KJ, Semmlow JL. Static vergence and accommodation: population norms and orthoptic effects. Doc. Ophthal. 1986: 62: l65-l79.
31. Hung GK, Ciuffreda KJ. Dual-mode control in the human accommodation system, Ophthal. Physiol. Optics 1988: 8:327-332.
32. Jiang BC, Tea YC, O'Donnell D. Changes in accommodative and vergence responses when viewing through near addition lenses. Optometry 2007, 78: 129-134.
33. Hung GK, Ciuffreda KJ. Models of refractive error development. In Hung GK and Ciuffreda KJ (eds) Models of the Visual System. Kluwer/Plenum, New York NY. 2002: 643-677.
34. Semmlow JL, Gauther GM, Vercher JL. Mechanisms of short-term saccadic adaptation. J Exper Psychol: Hum Percept Perform 1989: 15: 249-255.
35. Suchoff IB, Kapoor N, Ciuffreda KJ, Rutner D, Han ME, Craig S. The frequency of occurrence, types, and characteristics of visual field defects in acquired brain injury: a retrospective analysis. Optometry 2008: 79: 259-65.
36. Karnath H-O. Subjective body orientation in neglect and the interactive contribution of muscle proprioception and vestibular stimulation. Brain 1994: 117:101-112.
37. Kapoor N, Ciuffreda KJ, Suchoff IB. (2001) Egocentric localization in patients with visual neglect. In Suchoff IB, Ciuffreda KJ, and Kapoor N (eds) Visual and vestibular consequences of acquired brain injury. Optometric Extension Program Foundation Press, Santa Ana CA. 2001: 131-144.
38. Karnath H-O, Himmelbach M, Kuker W. The cortical substrate of visual extinction. Neuroreport 2003: 14: 437-442.
39. Maino D. Neuroplasticity: Teaching an old brain new tricks. Rev Optom 2009. 46(1):62-64,66-70.
40. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008 Feb;51(1):S225-39