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Treatment of Traumatic Brain Injury-Induced Oculomotor and Binocular Vision Dysfunctions with Vision Therapy

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ABSTRACT

Background: Patients with traumatic brain injury (TBI) commonly experience a collective group of oculomotor dysfunctions and visual disturbances that impact their activities of daily living. This includes deficits in accommodation, versions, vergence, and secondary strabismus due to a cranial nerve III, IV, or VI palsy. Photosensitivity, visual field loss, and ocular health complications may also result. TBI patients are likely to present to an optometrist for evaluation, treatment, and management of the oculomotor-related symptoms that other health care providers are unable effectively to resolve. Vision therapy (VT) can be used to treat the oculomotor disorders, binocular vision dysfunctions, and symptoms that a patient with TBI experiences. VT may be used in conjunction with optical correction involving prisms or tints to treat the symptoms of diplopia, field loss, or photosensitivity.

Case Report: An 18-year-old male college student endured a severe TBI while skiing. After three months of recovery, the patient suffered from constant double and blurred vision due to a partial cranial nerve (CN) III palsy and CN IV palsy in his left eye as well as an intermittent upbeat nystagmus in his right. After undergoing 12 weeks of active office-based vision therapy, the patient achieved clear and single vision at all ranges and was able to return to college the following semester.

Conclusion: This case demonstrates how the optometrist is an important part of the TBI-related rehabilitation team and can make unique management and treatment contributions that improve both visual function and quality of life for those suffering from a TBI.

Keywords: binocular vision, Glasgow Coma Scale, oculomotor dysfunction, traumatic brain injury, vision therapy

There are an estimated 1.7 million traumatic brain injuries (TBIs) in the United States annually; approximately 5.3 million Americans live with a TBI-related disability.[1] A TBI occurs when there is an external mechanical force (a bump, blow, or jolt to the head or body) that causes coup-contrecoup injuries and axonal shearing. TBIs are widely characterized as mild, moderate, or severe based on the Glasgow Coma Scale[2] (GCS) score that a patient is given upon presentation to the emergency department. The GCS score grades a person's ability to open their eyes, to respond verbally, or to make motor responses. The highest GCS score would be in a patient who could spontaneously open their eyes, respond verbally in an oriented sense, and obey motor commands; the lowest score would be an inability to open the eyes and no verbal or motor responses present.

A GCS score between 15 and 13 is considered a mild TBI (mTBI) and may cause temporary changes in brain function, including a change in mental status or consciousness. About 75% of TBIs that occur each year are concussions or other forms of mTBI.[3] Mild TBI does not always cause long-term disability; however, mTBI patients who experience symptoms such as headaches, dizziness, and nausea in the emergency department are more likely to have post-traumatic complaints such as headaches, dizziness, and drowsiness six months after their injury.[4] Most of the symptoms of mTBI resolve completely within three months of the brain injury, but up to 10% are symptoms that are persistent or permanent.[5] Many patients who suffer from persistent symptoms report improvements by one year post-injury but still suffer disabilities at work such as finding their work more tiring and an inability to maintain previous workloads. Mild TBI patients also report lower levels of life satisfaction one year post-injury.[6]

A GCS score between 12 and 8 is considered a moderate brain injury, and a score below 8 is considered severe. Moderate and severe traumatic brain injuries can result in bruising, torn tissues, bleeding, and other physical damages to the brain that can result in long-term complications or death. Severe TBIs are either closed or penetrating. Closed TBIs cause injury to the brain by movement of the brain within the skull, and penetrating TBIs occur when the brain is injured by a foreign object entering the skull. Sixty-five percent of individuals with moderate brain injury and 100% of patients with severe TBI will have a permanent disability.[7] One-third of severe TBI victims, or 52,000 people, die each year.[1]

The three groups at highest risk of incurring TBI are children aged 0 to 4 years, older adolescents aged 15 to 19 years, and adults aged 65 years and older. In all three age groups, males have higher TBI rates than females, particularly in males aged 0 to 4 years. Falls are the leading cause of TBI in children aged 0-4 years and in adults over 65 years. Motor vehicle injury is the leading cause of TBI-related deaths and is most common for adults aged 20 to 24 years.[1] Racial minorities and those of lower socioeconomic status suffer TBI rates 35% higher than other individuals.[8] Ethnic minorities have worse long-term outcomes and a higher mortality rate after TBI due to a lack of insurance. Typically, younger Caucasian patients with insurance, with a less severe TBI, and with fewer concomitant injuries will have better outcomes.[5,9]

Patients with a TBI may present to the optometric practice with variable symptoms and clinical findings.[10] Common oculomotor/binocular vision disorders associated with TBI are accommodation deficiencies, version and vergence dysfunctions, and strabismus and cranial nerve palsies.[11] Patients can also experience problems with visual field loss, photosensitivity, and eye health issues. While it is possible for oculomotor disorders to occur individually, it is more common for simultaneous visual dysfunctions to be present, complicating diagnosis, management, and treatment.[12] TBI-related oculomotor dysfunctions frequently lead to complaints of blurred vision, asthenopia, and diplopia; problems reading; or a combination of these symptoms. These symptoms make it difficult successfully to complete work, leisure activities, or activities of daily living efficiently and comfortably, causing loss of productivity and a reduced quality of life.

Vision therapy (VT) has long been established as an effective treatment option for oculomotor dysfunctions and binocular vision disorders in the general population as well as in those who have suffered a TBI. Office-based VT can effectively treat oculomotor dysfunctions that occur after a TBI event and can be an effective tool in helping TBI patients regain visual function and comfort for activities of daily living.[13-21]

Case Report

Patient History

AC, an 18-year-old white male, was referred to my office on March 8, 2011 by a rehabilitation center for a VT program to treat his diplopia and blurred vision. AC had suffered a severe TBI when he skied into a snow machine on December 4, 2010. AC was a college freshman, and, being highly motivated to recover, had established a goal of returning to school for the fall 2011 semester. AC had actively participated in adventure sports such as skateboarding, skiing, and snowboarding for years and hoped to return to them in a safer, reduced capacity.

When AC was admitted to the emergency department, his GCS score was 3. A computed tomography scan of the head revealed punctate contusions in his left temporal lobe and left tectum and a small intracranial hemorrhage in the interpeduncular cistern. Brain magnetic resonance imaging findings were reported to be consistent with diffuse axonal injury, with the largest lesion along the course of the left CN III nucleus. Innumerable foci of susceptibility were scattered throughout the gray/white matter junction and were consistent with the micro-hemorrhages.

A neuro-ophthalmological examination was performed on 1/24/2011 while AC was at a rehabilitation center. The neuro-ophthalmologist reported the following: AC was reported to be alert, oriented, communicative, and cooperative for testing. Corrected visual acuities were 20/70 with pinhole improvement to 20/50$^-$ OD, 20/20 without pinhole improvement OS. Color vision (Ishihara) testing showed correct identification of 8/8 plates OD, 8/8 plates OS. Amsler grid testing was normal OU. Pupils were unequal in size; the left pupil was fixed and dilated. There was no APD by reverse testing. External examination of the eyes and orbits was normal. The lids showed a 2-3 mm ptosis on the left. Examination of extraocular motility revealed -0.5 limitation adduction OS, -1 limitation elevation OS, and -3 limitation depression OS. There was also slight limitation of incyclotorsion OS. Pursuit and saccadic functions were normal. There was moderate amplitude, moderate frequency dissociated upbeat nystagmus OD. External ocular health was normal. Applanation tonometry revealed pressures of 15 mm OD and OS. Dilated fundus examination revealed normal optic nerves, maculae, and mid-peripheral retinae OU. The cup-to-disc ratios were 0.3 OU. Automated (Humphrey) visual field testing was performed reliably and found no field defects OU.

The neuro-ophthalmologist diagnosed AC with the following:

1. Left partial CN III palsy
2. Left CN IV palsy
3. Moderate amplitude, moderate frequency dissociated upbeat nystagmus OD

Neuro-ophthalmology recommendations were occlusion OS to eliminate diplopia and a follow-up exam in three months.

Examination Findings

At his first visit to my office in March, AC's chief complaints were intermittent diplopia that was both vertical and horizontal in nature, sensitivity to light outside, and blurred distance vision that was worse in his right eye than his left with his current glasses. AC reported that he preferred using his right eye when he was walking and his left eye when he was reading. Presenting spectacles were OD: -1.00-0.50x005 (20/100) and OS: -1.25 DS (20/20). The manifest refraction was OD: -2.50-1.00x010 and OS: -1.25 DS (20/20 OU). External examination revealed normal confrontation fields OU. His right pupil measured 4.0 mm, and his left pupil was fixed and dilated at 7.0 mm due to the partial left 3rd nerve palsy; there was no APD by reverse testing.

AC did not appreciate stereopsis on the Randot stereotest and reported 5 dots on Worth 4-dot testing at both distance and near. Extraocular muscle testing (versions) were full (no under- or overactions) in his right eye; his left eye demonstrated a full range of motion except for an underaction of the superior oblique muscle. Distance cover test through a trial frame of his manifest refraction revealed a 16$^{\Delta}$ constant left hypertropia and a 25$^{\Delta}$ constant left exotropia. Near cover test measured an 11$^{\Delta}$ constant left hypertropia and a 15$^{\Delta}$ constant left exotropia. An intermittent right upbeat nystagmus was observed, and a partial left ptosis was noted.

Accommodative amplitudes were measured through the trial frame by push-up method to obtain a free-space assessment. AC reported blur with his right eye at 7 cm (14.28 diopters) and blur with his left eye at 33 cm (3.03 diopters). The left side reduction was due to his partial left 3rd nerve palsy. Hofstetter's formula [15-0.25x(age of patient)] estimates that the lower limit of accommodation for an 18-year-old would be 10.5 diopters; however, research by Sterner in 2004 found that Hofstetter's formula overestimates monocular accommodative amplitudes an average of 3.5-3.6 diopters.[22]

Slit lamp examination was unremarkable OU. Applanation tonometry measured intraocular pressures of 17 mm Hg OU, and fundus evaluation was normal in both eyes, with cup-to-disc ratios of 0.3 OU.

AC reported that it was easier to maintain single vision at near than at far. On near point of convergence testing, he could first obtain single vision in free space on a small bead with an accommodative target at 35 inches (91 cm) with a chin-tip down. He could maintain single vision on the target up to 10 inches (25 cm), at which point the target broke, but he had to continue to tip his chin down. When he was prompted to maintain a normal head posture with no chin-tip down, he could maintain fusion to 10 inches (25 cm), but he reported that it took much greater effort.

Diagnoses

- Diplopia at both distance and near secondary to a left hypertropia (CN IV palsy) and a left exotropia (partial CN III palsy)
- Left underacting superior oblique muscle due to CN IV palsy
- Imbalanced accommodative amplitudes secondary to the partial CN III palsy
- Left partial ptosis from the partial CN III palsy
- Blurred vision secondary to under-corrected refractive error
- Photophobia secondary to TBI as well as from the fixed and dilated left pupil

Treatment Plan and Vision Therapy

Treatment options were presented to AC to provide immediate and long-term relief of his symptoms. Glasses were prescribed without a tint for indoor use, and prescription sunglasses were prescribed to reduce sensitivity to light outside. Fresnel 3M Press-on™ prisms for AC's vertical diplopia were discussed, but AC was highly motivated by the idea of the VT and wanted as few accommodations as possible during the therapy program. AC's personal goal was to complete the VT program by mid-summer (12 weeks) so that he could return to school in the fall. Due to his eagerness to start the therapy program, AC was prescribed a -2.00 diopter loose lens, and he was instructed on how to perform monocular minus lens rock exercises with the Hart chart at 10 feet with his left eye. He was also taught how to perform gross convergence with pencil push-ups so he could start to experience the sensation of convergence until the start of his therapy program one week later.

The goals of the VT program were as follows:

- Eliminate diplopia
- Balance the accommodative system between the eyes
- Improve free-space balance and coordination during visual tasks

All therapy sessions took place on a weekly basis, with one hour of in-office therapy and a daily home-based therapy program prescribed at the end of each in-office session. An ambitious goal of completing all therapy in 12 weeks was set so that AC could return to college for the fall semester.

Therapy Sessions #1-4

The goal of the first four therapy sessions was to reduce AC's diplopia by improving his convergence and accommodative skills. Tracking work was also introduced since he was a student and would be returning to heavy coursework in the fall. At the first therapy session, the following exercises were introduced as part of AC's in-office and home-based program:

- Ann Arbor tracking (monocular) to improve saccadic reading skills, with a goal to complete each paragraph in less than one minute without the motor support of underlining each line of letters.
- Marsden ball tracking (monocular) to improve pursuit eye movements, with a goal of completing 10 horizontal passes with smooth tracking while seated.
- Brock string to improve convergence skills.
- Minus lens rock (monocular, emphasis on left eye) to improve and to balance accommodative skills, with a goal to complete the full Hart Chart at 10 feet in less than one minute.
- +/-2.00 diopter flippers (monocular, emphasis on left eye) while reading to improve accommodative facility.
- Balance board (assisted) to increase body awareness and balance reactions.

At the end of the first four weeks of therapy, AC had met the prescribed goals for both Ann Arbor tracking and the Marsden ball. With his head in a normal position, AC was able to converge his eyes on a Brock string bead up to 2 inches (5 cm) from his nose, as well as jump between a near bead at 2 inches (5 cm) and one 18 inches (46 cm) away. He was also able to maintain clear, single vision on the Brock string bead while using +/-2.00 diopter flippers binocularly with the bead at 16 inches (40 cm). AC's accommodative system in his left eye was able to perform the minus lens rock with the Hart chart using a -3.00 diopter lens in less than one minute. AC had done so well on convergence and accommodative tasks that the opaque Lifesaver card for convergence was introduced on week #3, and in one week he was able to fuse and to clear the 3rd Lifesaver from the bottom but was unable to appreciate depth of the letters E and R. AC subjectively reported that monocularly using the +/-2.00 diopter flippers while reading was much easier. AC's balance improved on the balance board over the first four weeks; by week four he could keep a ball balanced in a groove in the board for 3-5 seconds as well as maintain balance while throwing and catching a 3 lb weighted ball at his midline.

AC reported that the headaches that he had experienced during the first three weeks of therapy had dissipated. His cover test measurement at distance was an intermittent 16^{Δ} left hypertropia and 14^{Δ} left exotropia. Cover test at near measured an intermittent 16^{Δ} left hypertropia and 10^{Δ} left exotropia. His accommodative amplitude (push-up) with his left eye was 8.33 D. At this point, AC requested that the Fresnel prism be placed on the left lens of one pair of his glasses to eliminate the intermittent vertical diplopia when he was working with his physical therapist on balance and gross muscular strengthening at the rehabilitation center. Based upon AC's cover test measurements and trial framing of vertical prism, AC felt most comfortable with 10^{Δ} of base-down prism over his left eye, so this Fresnel prism was placed on AC's left spectacle lens.

Therapy Sessions #5-7

The following therapy procedures were prescribed as part of AC's in-office and home-based therapy program for therapy sessions #5-7:

- Binocular Ann Arbor tracking (smaller print paragraphs) with a goal to complete each paragraph in less than one minute without the motor support of underlining each line of letters.
- Marsden ball tracking (binocular) with a goal of completing 20 smooth horizontal passes with smooth tracking while standing.
- Brock string work continued with the addition of +/-2.50 flippers and 8 BO/2 BI prism flippers.
- Lifesaver card was continued for convergence, and the clear divergence Lifesaver card was introduced.
- Minus lens rock continued (monocular, emphasis on left eye) with a -3.50 diopter lens.
- +/-2.50 flippers (monocular, emphasis on left eye) while reading.
- Monocular pursuits with the Brock string attached to the rotating pegboard.

As therapy demands increased, AC used his prism glasses at times during in-office and home-based therapy sessions when he was tired or struggling to fuse targets (primarily during binocular Brock string activities). Binocular Ann Arbor tracking was discontinued after week 5 because it was "too easy:" AC could complete the task with both eyes open in 40 seconds. AC continued to work on Brock string push-ups and "jump" exercises from the first four sessions with an emphasis on getting the strings to cross quickly and consistently at each bead. Lens and prism flippers were introduced with the Brock string to improve and to refine accommodation/vergence skills. The Lifesaver card for convergence was continued, and the clear divergence Lifesaver card was introduced to promote balance between AC's convergence and divergence systems. The monocular minus lens rock lens power was increased to -3.50 diopters and was still emphasized for AC's left eye. Accommodative facility flipper powers were increased to +/-2.50 for monocular use (emphasis left eye) to improve and to balance AC's accommodative facility skills while reading. Monocular pursuit exercises with the Brock string attached to the rotating pegboard (6 feet away) were introduced in-office to promote slow circular pursuit skills.

At the end of the seventh therapy session, AC was able to track the Marsden Ball smoothly for 20 passes binocularly while standing. With the Brock string, AC maintained his convergence skills up to 2 inches (5 cm) from his nose, and he gained more control during "jumps," getting the strings to cross at the beads quickly and consistently. AC was able to hold clear fusion on the Brock string beads at 16 inches (40 cm) while using +/-2.50 diopter flippers, as well as to obtain quick recovery of bead fusion with the 8 BO/2 BI prism flippers. AC continued his work on the Lifesaver cards and gained the ability to fuse the fourth, most demanding, Lifesaver on the convergence card and the second Lifesaver on the divergence card; he never appreciated depth of the letters on either card. Minus lens rock and +/-2.50 diopter flipper therapy continued primarily as home-based therapy, and AC reported that he was able successfully to use the -3.50 diopter lens with the Hart chart and the +/-2.50 flippers while reading. AC's monocular circular tracking exercises with the Brock string attached to the rotating pegboard proved more difficult for his right eye than for his left. AC worked to track and to jump between beads on the Brock string at 24 inches (61 cm) and 40 inches (101 cm) away from his nose as the string rotated with the rotating pegboard. AC's ability to maintain balance on the balance board while catching a 3 lb weighted ball continued to improve, and the ball started to be thrown randomly to his right and left. By the end of week 7, AC's accommodative amplitude (push-up) measurement with his left eye was 14 diopters, and he subjectively reported fewer symptoms of diplopia.

Therapy Sessions #8-12

Before the beginning of session #8, AC was fit into the following contact lenses:

OD: Ciba Focus Dailies for Astigmatism, B.C. 8.6, DIA. 14.2, -2.50-0.75x180

OS: Ciba Dailies, B.C. 8.6, DIA. 13.8, -1.25 DS

The contact lenses provided visual acuities of 20/20 in each eye. At his one-week follow-up, AC was experiencing good contact lens comfort and vision. His acuity remained at 20/20 in each eye, the contact lens fit was determined to be good, and his prescription was finalized. AC was given the option of having plano prescription glasses prescribed with base down Fresnel prism over his left lens for intermittent use, but he declined. At this point in his treatment, AC felt that he experienced diplopia so infrequently that it did not pose a functional problem.

Therapy sessions #8-12 introduced more free-space and motor work, including core stability to round out AC's therapy program. The following exercises were continued/introduced during AC's last four therapy sessions:

- Marsden ball (binocular) tracking while standing on a balance board or standing in "tree" yoga pose.
- Monocular Brock string pursuit rotations with rotating pegboard were continued; manual large (arm's length) diameter rotations with therapist holding/rotating the string were added.
- Binocular pursuits with the Brock string attached to the rotating pegboard for small rotations as well as large (arm's length) diameter rotations with the therapist holding/rotating the string were introduced.
- Brock string convergence work was continued primarily as part of AC's home-based therapy.
- Minus lens rock work was continued only as part of AC's home-based therapy; he continued to work with the -3.50 diopter lens.
- +/-2.50 flippers while reading (binocular).
- Core stability work with therapy ball sit-ups catching a 3 lb ball.

On week 8, AC started to work on Marsden ball tracking exercises with two separate balance techniques incorporated into his Marsden ball routine. One combination technique required AC to track the Marsden ball while maintaining balance on a balance board. The second combination technique required AC to track the Marsden ball while maintaining a standing yoga "tree" pose. "Tree" pose required AC to stand on one leg while his other leg was bent and his raised foot was tucked on the inside of the opposite thigh. Initially, AC had more trouble balancing on his left leg (2 seconds) than his right (10 seconds), but after practicing at home for one week, AC could balance on each leg equally well for 10 seconds while tracking horizontal passes of the Marsden ball. Monocular Brock string rotations with the rotating pegboard (6 feet away) and the newly introduced manual rotations continued, and AC reported that his circular pursuits started to equalize between his eyes by week 11. Binocular Brock string rotations with the rotating pegboard while maintaining convergence on the Brock string were introduced, with bead placement between 24 inches (61 cm) and 40 inches (101 cm). Intermittent vertical diplopia was reported when the bead was at its lowest point of rotation on the rotating pegboard. During manual large-diameter circular rotations with the Brock string, beads were placed at 24 inches (61 cm), 40 inches (101 cm), and 60 inches (152 cm); AC continued to experience intermittent vertical diplopia when the beads were in the lower one-third of his inferior field. The intermittent vertical diplopia did not fully resolve by week 12 unless AC was wearing his prism glasses. At week 12, AC could complete the Hart chart -3.50 diopter minus lens rock exercises successfully (45 seconds right eye; 50 seconds left eye). AC's basic Brock string (push-ups, jumps, +/-2.50 diopter flippers, and 8 BO/2 BI prism flippers) and minus lens rock exercises were continued but were emphasized more at home than in office so that expanded free space motor work could be introduced. Therapy ball sit-ups while catching a 3 lb weighted ball at his midline and to his right and left were introduced to improve AC's core stability.

Table 1: Pre- and Post-VT Results

	Pre-VT	Post-VT
Cover Test Distance	16^{Δ} constant left hypertropia 25^{Δ} constant left exotropia	10^{Δ} left hyperphoria 8^{Δ} exophoria
Cover Test Near	11^{Δ} constant left hypertropia 15^{Δ} constant left exotropia	10^{Δ} left hyperphoria 7^{Δ} exophoria
Randot Stereo Test	No forms	500" global stereopsis
Worth 4-Dot	5 dots at distance and near	4 dots at distance and near
Accommodative Amplitudes	OD: 14.28 diopters OS: 3.03 diopters	OD: 16 diopters OS: 14 diopters
Near Point of Convergence	Break/diplopia at 2.5 cm	Break/diplopia at 2.5 cm

Follow-Up Visit Post-Vision Therapy

AC reported to my office for his follow-up visit post-VT program on June 13, 2011. He reported that he only experienced transient vertical diplopia in downgaze and had completely discontinued wearing his Fresnel prism glasses. Cover test measurement at distance was 10^{Δ} left hyperphoria and 8^{Δ} exophoria. His near cover test revealed 10^{Δ} left hyperphoria and 7^{Δ} exophoria. An intermittent upbeat nystagmus was still noted in his right eye during cover testing at distance and near. During near point of convergence testing, AC reported a break in fusion of the target at 1 inch (2.5 cm) and could recover fusion when the target was moved back to 2 inches (5cm). AC reported 4 dots at distance and near with Worth 4-dot testing. Randot stereotest recorded 500" of global stereopsis. Accommodative amplitudes by push-up were 6 cm (16 diopters) in his right eye and 7 cm (14 diopters) in his left. AC's monocular accommodative facility measurements with +/-2.00 diopter flippers and a 20/40 target at 16 inches (40 cm) were 10 cycles per minute in the right eye and 8.5 cycles per minute in the left. The expected value for patients between 13 and 30 years of age is 11 cycles per minute (+/-5 cycles).[23] AC's pre- and post-therapy results can be seen in Table 1. AC was encouraged to continue his home-based vision therapy at least three times per week to maintain solid control over his convergence and accommodative skills.

Discussion

Vision therapy has been shown to benefit patients experiencing oculomotor symptoms from a TBI. Even when VT is implemented years after the patient's accident, it can improve visual function.[18-21] Plasticity is the brain's ability to reorganize itself by forming new neural connections during development and after injury or disease. This process starts as soon as one hour following diminished input to a portion of the somatomotor cortex and may take weeks or years to complete.[24] Recent research has also shown that VT can evoke cortical activity changes in the brain.[25]

Patients who experience a TBI are likely to have visual or oculomotor dysfunctions that impact their activities of daily living long after their accident.[26] Severe disorders of the visual system are often discovered immediately, but less severe forms of visual dysfunction can take longer to identify and to diagnose. The symptomatology experienced by a patient after a TBI can be variable but typically presents as asthenopia, headaches, diplopia, blurred vision, problems reading, field loss, or a combination of these symptoms.[27] Immediate relief can be provided by the optometrist through optical prescriptions for some symptoms: glasses to correct an uncorrected refractive error, bifocals to assist with accommodative disorders, prism glasses to eliminate diplopia or to assist with field loss, sunglasses if the patient is photophobic outdoors, or gradient tint glasses if the patient is sensitive to overhead lighting indoors. VT can provide long-term results and eliminate many, if not all, of the ocular symptoms suffered by the TBI patient when the symptoms they experience are due to convergence insufficiency; deficits in fixation, pursuits, and saccades; problems with steady version and vergence skills; accommodative disorders; and strabismus from cranial nerve palsies.[18,19]

During the initial assessment of a patient who has suffered a TBI, a full medical history of the TBI and post-injury problems experienced by the patient should be obtained. Clinicians should consider collecting as much medical history as possible prior to the evaluation of the TBI patient and book an extended appointment based on the patient's history and level of function. Extra time allows the examiner to prepare a clear direction for the examination and reduces scheduling conflicts when TBI patients are unable efficiently to perform the required visual tests due to poor understanding of directions or variable exam findings; less time may be necessary for patients with moderate to severe TBIs that are more medically involved and who are unable to sit and visually concentrate for extended periods of time.

A therapy program to address the oculomotor problems resulting from a TBI starts by working to improve monocular fixation, monocular pursuits, and monocular saccades, much like those undergoing VT without brain injury. A patient's physical status must be considered before starting fixation, pursuit, and saccade therapy. Patients who have generalized gross motor weakness, who fatigue easily, or who have partial paralysis may need extra support and should start this level of therapy supine on the floor where their body is well supported and eye-related exercises are isolated. As a patient's gross motor skills improve, the patient can start performing VT while sitting supported in a chair before finally moving to therapy while standing.

Muscle limitations due to paresis that result in diplopia can be treated initially with Fresnel prisms or prism ground into the patient's lenses. If the patient's ocular misalignment requires higher amounts of prism (20^{Δ} or higher), the level of reduced acuity and contrast sensitivity can be problematic, so the clinician should always try to split the prism between the lenses. This is especially true with Fresnel prisms that have been found to degrade acuity and contrast sensitivity in higher prismatic values.[28,29]

Disorders of accommodation occur in 41.1% of patients with TBI.[11] As with disorders of fixation, pursuits, and saccades, accommodation disorders should be treated monocularly until both eyes can accommodate equally before introducing binocular accommodative work. Convergence insufficiency is present in 42.5% of patients with TBI and can be addressed in tandem with binocular accommodation therapy.[11] Vergence work can begin when the patient can fuse an image seen by both eyes without diplopia; this may require temporary use of prisms to assist fusion.

As basic oculomotor and binocular vision skills of the patient improve, free space activities can begin to make vision skills more habitual as the patient's gross motor system is incorporated into therapy. In AC's case, Marsden ball work, Brock string activities, general balance work, and core stability exercises combined gross motor work into his VT.

Mild TBI is eight times more common than moderate or severe TBI, and 70-90% of patients who present to emergency departments have mTBI.[7] AC's recovery is profound in that he presented to the emergency department with a GCS score of 3, representing a severe TBI. There are many factors that contributed to AC's success: AC was young, healthy, and highly motivated to succeed; he had a strong family support network; and he had a complete medical/rehabilitation team including occupational therapists, physical therapists, a neuro-ophthalmologist, and an optometrist providing a VT program. AC also had excellent primary and secondary insurance that helped pay for most of the medical services, reducing the financial stress on his family and allowing them to focus on his recovery. AC spent hours on his home-based therapy each week (sometimes hours each day) working to improve his oculomotor skills. AC also demonstrated a high level of visual adaptability. When he presented at his first exam, he had already developed an adaptive visual suspension mechanism to cope with his diplopia: he used his right eye when he was walking and his left eye when he was sitting down. AC's left hyper deviation never fully resolved, and after his 12th therapy session, he reported that he experienced vertical diplopia when he looked "35 degrees below horizontal." AC was aware and could clearly verbalize that he maintained fusion with both eyes during activities like sports and driving, but he still preferred using his left eye for homework and reading. AC's therapy program maximized his abilities, but it did not directly resolve the nerve pathology. He was left with the option of using glasses with vertical prism as needed post-therapy, but he chose not to pursue the option.

This case demonstrates that the optometrist can play a major role in the rehabilitation of patients who have suffered a TBI. Additionally, it shows how VT can improve functional vision skills in patients with TBI, reduce their symptoms, and help them with their activities of daily living.

Conclusion

When the health of the patient has stabilized after a TBI, they can be good candidates for an office-based program of VT to reduce symptoms from their impacted oculomotor system. Oculomotor dysfunctions associated with TBI may be more severe and complex than what are treated in traditional VT patients, but the symptoms these patients experience are similar and may be noticed immediately or months after the accident. Deficits in fixation, pursuits, saccades, accommodation, versions, or vergence, as well as the development of strabismus or cranial nerve palsies, are common post-TBI and should be addressed by the patient's optometrist. There are many factors that contribute to the success of a patient's therapy program, including the severity of the brain injury, the patient's level of commitment to the therapy program, family support, the quality of the patient's insurance, and their socioeconomic status. This case demonstrates how VT can be used effectively as a part of a comprehensive rehabilitation program to treat the oculomotor symptoms associated with TBI and to help a patient return to a highly functional quality of life.

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