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VISION TRAINING TO IMPROVE CLASSROOM ENDURANCE POST-TBI: A CASE STUDY WITH A 26-YEAR-OLD FEMALE

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ABSTRACT

Background: Concussions, also referred to as a mild traumatic brain injury (mTBI), can present a multitude of symptoms due to the complex pathophysiology incurred by the brain. It is known that these mTBI-induced symptoms, when left unresolved, can lead to post-concussive syndrome (PCS). Commonly, these patients complain of vision-related dysfunctions. These dysfunctions interrupt patients' everyday lives, including those of students, when participating in the classroom due to the heavy visual involvement. Numerous vision therapies and management strategies have been successful for the treatment of mTBI-induced visual-related symptoms such as exotropia, suppression, and oculomotor dysfunction. Vision training successfully improves oculomotor endurance, allowing patients to maintain focus for long periods and mitigate against suppression.

Case Report: This report describes a 26-year-old female presenting with activity-induced sensory overload, specifically in the setting of her college classroom lectures. The patient described symptoms appearing as headache, fatigue, and blurred vision. Upon initial examination, she was determined to have a left eye exophoria with fatigue-induced left eye suppression and left eye lateral abduction deficiencies. A personalized action plan was designed to improve left-right oculomotor symmetry and endurance and mitigate against suppression through a weekly structured vision training program. In this 7-week program, individual and dual eye saccadic exercises improved, with both eye horizontal saccades improving from 26 characters read aloud per minute to 36 characters read out loud per minute. With these regular vision training sessions, the patient displayed improved oculomotor endurance, decreased suppression with prolonged activity, and better dual-eye coordination. After the post-vision training program, the patient could attend her college lectures without invoking symptoms.

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Conclusions: As part of an mTBI-induced visual dysfunction therapy program, vision training can restore oculomotor endurance. This improved oculomotor endurance can mitigate fatigue-induced visual symptoms exacerbated in academic settings like the classroom.

Keywords: suppression; exophoria; vision training; Brock string; saccades; concussions; mTBI

INTRODUCTION

Concussions, also referred to as a mild traumatic brain injury (mTBI), can present with a multitude of symptoms due to the complex pathophysiology incurred by the brain.[1,2] It is known that these mTBI-induced symptoms, when left unresolved, can lead to post-concussive syndrome (PCS).[2-5] Commonly, these patients complain of concentration and attention deficits, mild frequent headaches, and more.[2-5] Despite the need for more research into post-concussive pathophysiology, some literature suggests a subset of these symptoms could be untreated vision-related dysfunctions. These dysfunctions interrupt patients' everyday lives, including those of students, when participating in the classroom due to the heavy visual involvement.[6,7] Numerous vision therapies and management strategies have been successful in the treatment of mTBI-induced visual-related symptoms such as exotropia, suppression, and oculomotor dysfunction.[8-10] Vision training improves oculomotor endurance, allows patients to focus for long periods, and mitigates suppression.[8-10] This case report presents the methods and time course for a vision training regimen used to treat a patient with classroom-induced oculomotor fatigue post-TBI.

CASE REPORT

A 26-year-old female contacted the University of Cincinnati's Sports Medicine Department to mitigate classroom-induced fatigue following a traumatic brain injury. She reported difficulty completing a full day of classes without shutting down. During the initial consultation, the patient was found to have a left eye exophoria and lateral abduction deficiencies, resulting in fatigue-induced suppression of the left eye and convergence difficulties.

We performed a series of examinations before starting her vision training program. These included a convergence and divergence assessment, a near/far assessment, and Brock string testing.

INITIAL CLINICAL OBSERVATIONS

The patient presented with a left eye exophoria and lateral abduction deficiency during the initial clinical observations. She was found to have left eye excursions while abducting and fatigue-induced suppression as the assessment progressed.

A horizontal scanning saccade assessment was recorded from left-to-right at 27 characters called out-loud per minute (Figure 1). Near point of convergence was performed, and the left eye was observed to be exophoric while the patient reported blurring. Binocular divergence was adequate; however, when occluding the right eye, course abduction of the left eye was observed. During the near/far assessment, asymmetric abduction and left eye excursions were observed. The Brock string showed no initial signs of suppression; however, during a repeat Brock string test at the end of the assessment, the patient reported difficulty seeing two strings indicating fatigue-induced suppression. Based on these results, a personalized action plan was designed to improve oculomotor symmetry and endurance.

TREATMENT

The initial action plan was designed to improve oculomotor endurance, to mitigate and minimize fatigue-induced suppression of the left eye, and

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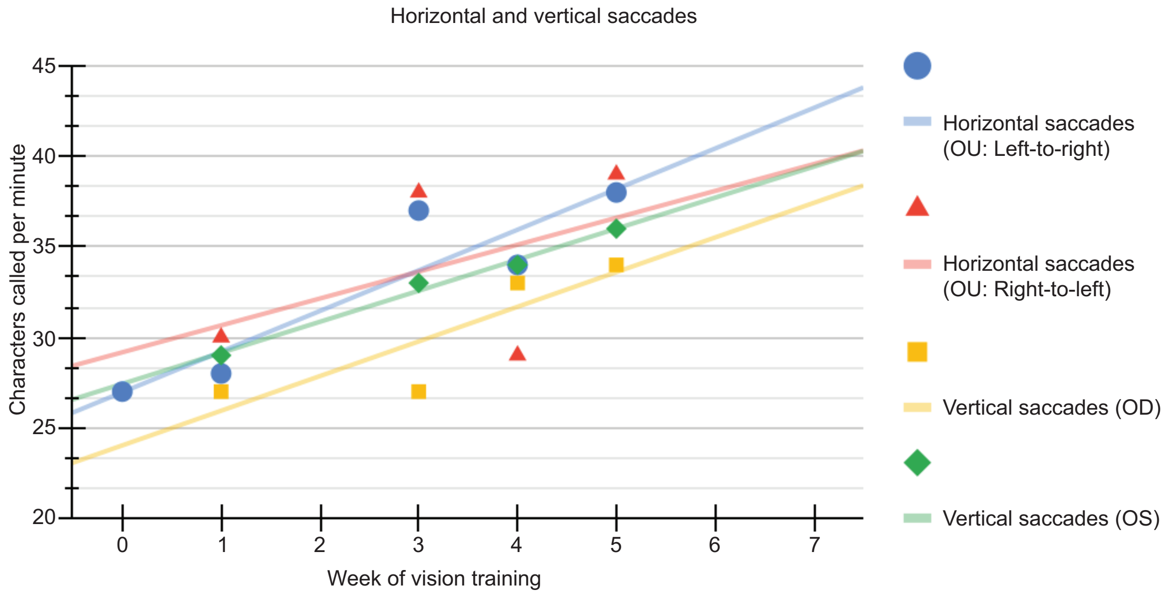
FIG. 1 Results from the weekly horizontal saccades for both eyes moving from left-to-right and from right to left, and single eye vertical saccades moving from top to bottom. Week 0 is the initial examination. Note that there was no data recorded for week 6 and week 7 because vision training progressed beyond saccadic exercises to tranaglyphs. OU = both eyes; OD = right eye; OS = left eye.



to improve left-right oculomotor symmetry while engaging the accommodative system.[8] The patient was scheduled to come in for training and rehabilitation sessions once per week for a minimum of 30 minutes up to 1 hour.[11,12] Training sessions routinely began with monocular circle smooth pursuits using a rotating apparatus followed by two sets of binocular figure-eight smooth pursuits: the first starting from the left moving to the right in a figure-eight pattern and the second set starting from the right moving to the left in a figure-eight pattern. This was implemented to act as a warm-up for the oculomotor muscles before training exercises. Medial isometric hold exercises were introduced as a warm-up during the third week of the vision training program once both smooth pursuit warm-up exercises (circles and figure-eights) were qualitatively deemed non-fatiguing.[11,12]

These warm-ups, especially the medial holds, were implemented to elongate the lateral abductors of the left eye, primarily the lateral rectus, before engaging in saccadic eye exercises. This is because the initial examination suggested that the patient's left eye exophoria was due to a shortening, or more contracted, lateral rectus at baseline post-injury, leading to an abnormal tension-length function.[13,14] Therefore, by medially overextending the lateral rectus muscle the tension-length function will stretch, leading to a more relaxed lateral abductor at baseline and allowing the subsequent vision training exercises to work symmetrically.[13,14]

Following the warm-up, weekly training sessions predominantly included Brock string and both horizontal and vertical saccade exercises performed monocularly and binocularly.[8] These exercises were chosen because they translated to visual functioning while in the classroom through the accommodative and convergence systems (looking up at the PowerPoint and back down at one's notes to write), and with oculomotor strength and conditioning (scanning the PowerPoint and back and forth from the professor to the notes, etc.).

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We routinely used a monocular Brock string exercise to engage in dynamic adduction of the affected left eye with accommodation.[8] This technique improves the endurance of the affected eye and can serve to monitor the symmetry of left-right eye performance as well as fatigue-induced suppression. As therapy sessions progressed, Brock string exercises were often performed off-center to the left for further left adduction and tracking.[16,17]

Therapy sessions included a multifaceted rotating wheel with tracking target, saccadic eye charts, both coarse and thin Brock strings, tranoglyphs, and strobe glasses. Not all exercises were done each week, as tranoglyphs replaced saccade exercises once they were performed competently and without inducing symptoms.[11,12] Strobe glasses were used to enhance the difficulty of other exercises, forcing the patient to perform with less and distracted visual information.

The methods used to perform these rehabilitation and training exercises are standard and have previously been published.[8,10] These include Brock string, vergence training, saccades, strobe glasses, and accommodation training. Each session was designed to systematically progress the exercises to demand more visual and cognitive functioning, as well as to keep the patient challenged but engaged in achieving oculomotor conditioning.[11,12]

TRAINING AND REHABILITATION METHODS

The length of each training session was set to begin at 30 minutes and progress up to one hour by the final day. Although, these times could vary depending on how the patient feels on the training day. The second training session was the only session below the minimum 30-minute session because the patient reported having a headache and feeling nauseous before beginning the warm-up exercises, and thus was cut short at 20 to 25 minutes to mitigate the early onset of fatigue-induced symptoms. After consulting with the patient concerning her discomfort and fatigue, the next couple sessions progressed from 30 minutes to 45 minutes and ended with the last two sessions being one hour.

VISION TRAINING

Week 1: Upon the first vision training session, the patient reported having a headache before arrival for the session, although she could appreciate two strings with the Brock string and complete the entire session without developing or exacerbating further symptoms. Both monocular circular and binocular figure-eight smooth pursuits were performed for 45 seconds. The Brock string training was executed in one-minute increments, and the average number of cycles per minute (cpm) was recorded at 4.25 cpm (Figure 2). Both eye horizontal saccades were evaluated during the initial examination in one-minute increments, and the number of characters called outloud per minute (chpm) was recorded to be 27chpm (Figure 1). During this first training, the average both of eye horizontal saccades was recorded at 29chpm.

Week 2: The vision training session was altered because the patient reported a headache and nausea before arrival. Instead of a 30-minute session, only 20 to 25 minutes of training occurred. The monocular circular smooth pursuit exercise was increased to 60 seconds, but the binocular figure-eight smooth pursuit exercise was decreased to 30 seconds. The Brock string training improved to an average of 4.6 cpm (Figure 2).

Week 3: After performing both smooth pursuit warm up exercises that increased to 75 seconds, monocular medial holds were introduced and completed at 3 sets of 10 seconds. Brock string training continued and significantly improved from the initial average of 4.25 cpm to an average of 5.9 cpm ($p \leq 0.05$; Figure 2). Both eye horizontal saccade exercises also improved from the initial average of 27 chpm to 37.5 chpm ($p \leq 0.01$; Figure 1).

Week 4: The patient presented to weekly vision training with "brain fog" and nausea. She could push through and completed smooth pursuit drills at 85 seconds followed by 5 sets of 10-second monocular medial

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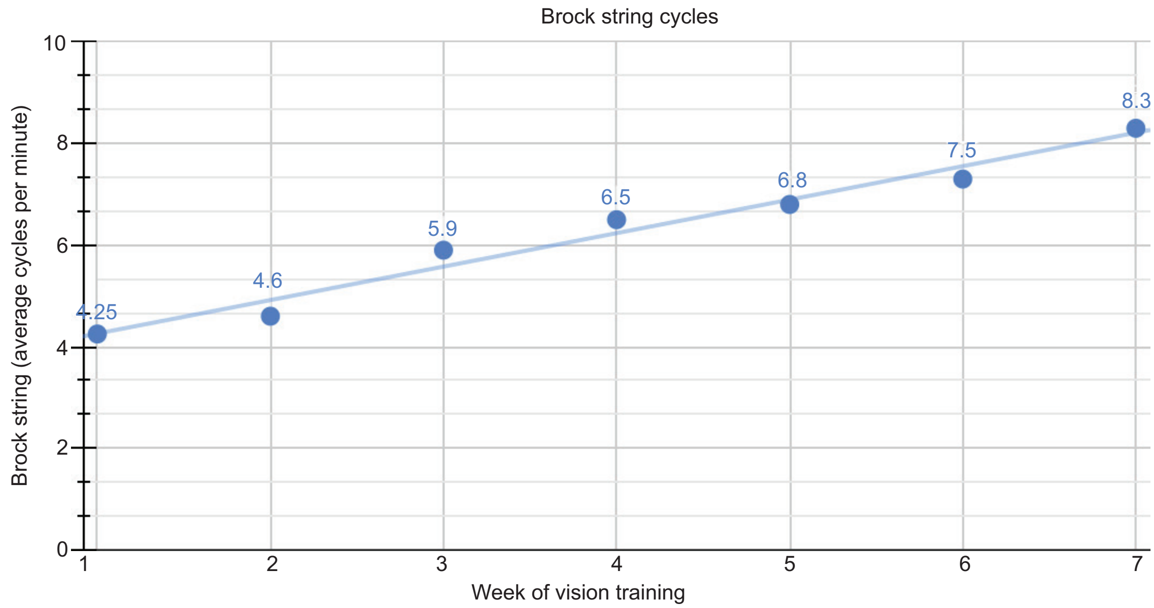
FIG. 2 Relationship between Brock string weekly scores to weeks of vision training program.



holds. Brock string results improved to an average of 6.5 cpm ($p \leq 0.01$; Figure 2). Vertical saccade exercises significantly improved from the initial average of 28 chpm to an average of 33.5 chpm ($p \leq 0.05$; Figure 1). Alternating and offset horizontal saccadic exercises were introduced as a progression from today's regular saccades. Both eye horizontal saccades decreased to 31.5 chpm (Figure 1). The patient claims that the offset saccades induced oculomotor fatigue but reported no exacerbation of symptoms.

Week 5: Both smooth pursuit exercises were increased to 95 seconds, followed by an increase in monocular medial holds to 7 sets of 15 seconds. Brock string training improved to an average of 6.8 cpm ($p \leq 0.01$; Figure 2). This was also the final week for both horizontal and vertical saccade exercises, where the horizontal saccades significantly improved up to an average of 38.5chpm ($p \leq 0.01$; Figure 1) and vertical saccades significantly improved up to an average of 35 chpm ($p \leq 0.05$; Figure 1). Tranoglyphs were introduced after the saccade exercises were completed and performed at level 1 for 5 sets of 20 seconds, and at level 2 for 5 sets of 20 seconds. The patient reports feeling better during her in-person coursework and lectures.

Week 6: Both smooth pursuit exercises were increased to 105 seconds, followed by an increase in monocular medial holds to 7 sets of 20 seconds. Brock string training significantly improved compared to the initial average of 4.25 cpm to 7.3 cpm ($p \leq 0.01$; Figure 2). Tranoglyph exercises also progressed up to level 4, with all levels performed for 5 sets of 30 seconds.

Week 7: The final week of vision training increased the smooth pursuit exercises to 120 seconds. Medial holds also increased to 7 sets of 30 seconds. The final Brock string training significantly improved from the initial average of 4.25 cpm to an average of 8.3 cpm ($p \leq 0.001$; Figure 2). Tranoglyphs stayed at levels 1 through 4, but the time of the exercise increased to 40 seconds. At the conclusion of this week, the patient expressed that she has been feeling "much better" while in the classroom, participating in her classes and taking notes.

DISCUSSION

This case study presented the vision training program and results for a 26-year-old female with a left eye exophoria, left eye lateral abduction

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deficiency, and fatigue-induced left eye suppression (Table 1). The patient participated in a 7-week, on-site vision training rehabilitation program designed to improve oculomotor endurance, decrease suppression with prolonged visual activity, and improve duel eye coordination. Her personalized training program consisted of oculomotor endurance, Brock string, and saccadic eye chart training. Monocular circle smooth pursuits and medial isometric holds were utilized to warm-up and condition the oculomotor muscles while stretching the left eye's lateral rectus to promote adduction and mitigate saccadic incursions during abduction. The Brock strong was used to strengthen the accommodative and convergence systems while in a symptom-provoking setting such as the classroom. Monocular Brock string training was further utilized to up train accommodation in the affected left eye, and it was continually progressed to move off-center to the left to further train left adduction and tracking. Vertical and horizontal saccadic eye movement training was utilized to improve fixation speed and accuracy, specifically in the setting of her college classroom lectures while shifting her gaze from scanning the presentation back down to her notebook. Throughout the 7-week progression of the rehabilitation program, the patient demonstrated improvements in both the clinic and classroom. These benefits included enhanced static and dynamic oculomotor endurance, minimized fatigue-induced suppression of the left eye, improved left-right oculomotor symmetry while engaging the accommodative system, and the ability to participate and excel in her daily college lecture schedule without evoking symptoms.

TABLE 1 Vision Training Results - Initial and at The End of Training

Vision Training Component	Initial	End of Training
Monocular Smooth Pursuits (Circle)	45 sec	120 sec
Binocular Smooth Pursuits (Figure-Eight)	45 sec	120 sec
Brock String (Binocular)	4.25 cpm	8.3 cpm
Horizontal Saccades (OU; LTR)	27 chpm	38 chpm
Vertical Saccades (OS; TTB)	29 chpm	36 chpm
Vertical Saccades (OD; TTB)	27 chpm	34 chpm

OU: both eyes, OS: left eye, OD: right eye, LTR: left-to-right, TTB: top-to-bottom, CMP: cycles per minute, CHPM: characters per minute.

The patient's binocular Brock string and vertical and horizontal saccade exercise scores significantly improved over the course of the rehabilitation program. The patient's number of cycles per minute on the Brock string significantly increased from 4.25 cpm to 8.3 cpm ($p \leq 0.001$). Additionally, the patient's characters read per minute during saccadic eye exercises significantly improved from an average of 27 chpm to 38.5 chpm ($p \leq 0.01$) for horizontal saccades and an average of 28 chpm to 35chpm ($p \leq 0.05$) for vertical saccades. These significant improvements represent the patient's heightened ability to smoothly transition her eyes from target to target (PowerPoint and notebook) quickly while also retaining more information from the presentation. These results also show improved oculomotor symmetry and discipline of both eyes and the left eye individually.

Improvement in oculomotor endurance was also noted as both monocular and binocular smooth pursuit exercises increased from 45 seconds to 120 seconds, and medial isometric holds increased from 3 sets of 10 seconds to 7 sets of 30 seconds. While these exercises primarily served as a warm-up for the oculomotor muscles and to elongate the identified contracted lateral rectus of the left eye, the continuous training improved the endurance of the left eye oculomotor muscles and mitigated fatigue-induced suppression identified during the initial consultation.

Throughout the rehabilitation program, dynamic adduction and stretching the lateral rectus of the left eye was an area of focus to mitigate the patient's left eye exophoria. This was accomplished using constraint-induced therapy principles[11,12,18]

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during monocular Brock string and saccadic exercises. By occluding the right eye, the patient was forced to adduct her left eye to complete the prescribed exercise. Through variation of the rehabilitation exercises, we could mitigate the left eye exophoria while also improving left-right oculomotor symmetry.

In addition to improvements in the rehabilitation exercises, during the 5-week session the patient reported feeling improvements during her in-person coursework and lectures. The oculomotor fatigue and decreased performance experienced by the patient while in the classroom likely resulted from the asymmetry of the patient's eyes thus leading to conflicting input being received by her brain. Through a targeted vision training rehabilitation program, the patient could diminish her left eye exophoria and improve left-right eye symmetry to provide consistent and uniform input to her brain. We believe that activating the brainstem, basal forebrain, and neuromodulators, including dopamine and serotonin, facilitates and strengthens the synaptic changes that underlie this training effect.[19,20,21] As a result of the consistent training, the brain's plasticity produced new synaptic circuitry, resulting in improved oculomotor performance[22] and therefore improved classroom performance for this patient.

We believe that a personalized vision training rehabilitation plan can treat and mitigate mTBI-induced symptoms such as an exophoria, extraocular muscle deficiencies, binocular asymmetry, and fatigue-induced suppression. As a result of the vision training rehabilitation plan, our patient displayed improved oculomotor performance, decreased suppression with prolonged activity, and better dual-eye coordination in a classroom setting. However, an extended vision training may be needed to maintain the oculomotor improvements established over the 7-week program due to the risk of muscle weakness and atrophy.[6]. Following the patient's exit interview, she was provided with an at-home exercise program and advised to continue with the exercises beyond her in-clinic sessions.

CONCLUSION

We conclude that vision training, as a part of an mTBI-induced visual dysfunction therapy program, can restore oculomotor endurance. This improved oculomotor endurance can mitigate fatigue-induced visual symptoms exacerbated in academic settings like the classroom. After seven weeks of personalized vision training, classroom endurance and ability improved substantially in a 26-year-old student post-TBI. The functional results include diminished exophoria, eye symmetry, and oculomotor endurance.

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