

OCULOMOTOR DYSFUNCTIONS, THEIR REMEDIATION, AND READING-RELATED PROBLEMS IN MILD TRAUMATIC BRAIN INJURY

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Abstract

Reading is a complex task involving a wide range of functions and abilities that are both vision and non-vision-based. Accurate eye movements are essential for efficient reading. Hence, if oculomotor control is impaired by traumatic brain injury (TBI), reading will likely be adversely affected.

We overview three studies conducted by our research group. These involved versional oculomotor dysfunctions, their related reading problems, and remediation in a group of visually symptomatic patients with mild TBI. The results have shown that in a large clinical sample (n=160), approximately 90% had one or more oculomotor deficits, such as convergence insufficiency or abnormal saccadic tracking, with the potential to impair reading performance. Thirty-three of this same clinical sample completed a program of vision therapy. Ninety percent of these subjects exhibited improvement in at least one related sign and one related symptom. Lastly, in a small (n=9) cohort of laboratory-tested, symptomatic subjects with oculomotor-based reading problems, all improved their overall reading performance and versional eye tracking ability, as assessed objectively and subjectively following basic versional training.

We conclude that oculomotor dysfunctions are common in individuals with mild TBI. The positive vision therapy findings demonstrate the presence of considerable

residual neuroplasticity in adults with mild traumatic brain injury. Optometric vision therapy should be instituted in visually symptomatic patients with TBI who manifest oculomotor-based reading dysfunctions.

Key Words

mild traumatic brain injury, motor learning, oculomotor dysfunctions, oculomotor plasticity, oculomotor rehabilitation, reading, vision therapy

INTRODUCTION

Readings is a complex activity involving a range of functions and abilities, including oculomotor, sensory, cognitive, and attentional aspects, as well as their integration.¹ Thus, if one or more of these control areas are impaired, for example by traumatic brain injury (TBI), reading is likely to be adversely affected.²⁻⁵

Our particular domain of interest is oculomotor control as it relates to reading. Although all of the oculomotor subsystems are involved in reading when considered over a wide range of viewing conditions,⁶ there are three primary types of eye movements that participate in reading at all times:

1. *saccades*, that rapidly shift the eyes from one word to another,
2. *fixation*, that maintains stable gaze during the reading pauses, and
3. *vergence*, that maintains binocular alignment during the fixational reading pauses and the intervening saccadic trajectories.

If any one of these three primary eye movement types is adversely affected by TBI, reading ability will be impaired.⁶ And, if other oculomotor subsystems are affected (e.g., the vestibular system), or if

accommodation becomes dysfunctional, reading rate and reading efficiency will be further degraded.^{1,6}

TBI has three primary etiologies: diffuse axonal injury, coup-contrecoup injury, and penetrating injury.⁷ Consequently, large areas of the brain are impacted, with resultant multi-faceted deficits of vision occurring. Moreover, since six of the 12 cranial nerves deal with vision, it is not surprising that a range of vision functions, including reading, are adversely impacted.

In the present paper, three sets of studies conducted in our brain injury clinical research unit over the past few years will be discussed. These involved oculomotor-based vision dysfunctions, their remediation, and related reading problems in visually-symptomatic patients with mild TBI. Key diagnostic and therapeutic aspects will be emphasized.

QUESTION 1:

What categories of oculomotor dysfunction were found, and how common were they?

In one retrospective study,⁸ oculomotor dysfunctions were divided into five broad diagnostic categories: accommodation, version, vergence, strabismus, and cranial nerve (CN) palsy. Based on a computer query spanning the years 2000-2003 in our clinic, 160 patients with mild TBI were found. Their optometric and medical records were reviewed in detail by three doctors from this clinic.

In Table 1, the percentage of patients manifesting an oculomotor dysfunction, as well as the most common anomaly found in each category, are presented. These ranged from approximately 7% to 56%, with each frequency of occurrence (FO) for a specific diagnostic category. These FOs are many times greater than that found in the general, non-TBI clinic

population.⁹ Most notably, the high FO of vergence, saccade, and accommodative dysfunctions is consistent with the high FO of oculomotor-based reading problems reported elsewhere in this population.²⁻⁵ Furthermore, 90% of the individuals in this large TBI sample manifested a deficit in one or more of these five categories. Thus, nearly all of these visually-symptomatic patients with mild TBI presented with one or more oculomotor deficits, with nearly all of these deficits having the potential to affect the reading process adversely²⁻⁵.

QUESTION 2:

What oculomotor-based signs and symptoms were found, and could they be remediated by conventional optometric vision therapy?"

In another retrospective study,¹⁰ the optometric and medical records from the same 160 patients with mild TBI were evaluated. Those 33 who were recommended and had completed their conventional optometric vision therapy (VT) for version and/or vergence dysfunctions were analyzed with respect to the presenting signs and symptoms, as well as treatment success rate. These patients received between 10 and 30 in-office VT sessions over a 2-8 month period, with each session lasting 45 minutes. Thus, the total in-office training time ranged from 4.5-13.5 hours. In addition, all received 10 minutes of daily home training related to their areas of oculomotor deficit.¹¹ The total home training time ranged from 10-40 hours.

The most common vision symptoms prior to VT related to near work and are presented in Table 2. Ocular motility difficulty related to reading had the greatest frequency (~80%). The most common clinically significant signs are presented in Table 3. Receded nearpoint of convergence and abnormal saccadic tracking (as measured by the Developmental Eye Movement Test (DEM)[®]) each accounted for ~70%.

If one invokes a therapeutic criterion of having at least one sign and one symptom, either to normalize or manifest marked improvement, the treatment success was 90%. Thus, optometric VT was efficacious and provided a considerable degree of satisfaction in these once highly symptomatic patients with TBI.

Further detailed analyses were performed on the original data sample (n=33) with

Table 1.
Summary of the percentage of individuals with TBI (n=160; ages 8-91 yrs) within a given category of ocular motor dysfunction and the most common anomaly present. Adapted from Ciuffreda et al⁸

Ocular motor dysfunction	TBI (%)	Most common anomaly
Accommodation	41.1	Accommodative insufficiency
Version	51.3	Deficits of saccades
Vergence	56.3	Convergence insufficiency
Strabismus	25.6	Strabismus at near
CN Palsy	6.9	CN III

Table 2.
Major symptoms initially reported by individuals with TBI (n=33; ages 40+ years).
Some persons may have presented with more than one symptom.

Symptom	Number of patients reporting the symptom
Ocular motility difficulty when reading	27
Eyestrain	18
Diplopia (at near more so than far viewing distances)	18
Headaches	11

Table 3.
Major clinically significant signs initially found in individuals with TBI (n=33; ages 40+ years).
Some persons may have presented with more than one sign.

Sign	Number of patients with the sign
Receded near point of convergence	23
Abnormal saccadic tracking	23
Reduced near convergence (BO) range	16
Reduced near vergence ranges	9

Table 4.
Number of reported vision symptoms in TBI patients (n=33; ages 40+ years)

Number of Vision Symptoms	Pre-Therapy number of patients reporting symptoms	Post-Therapy number of patients reporting symptoms
5	1	0
4	7	0
3	11	1
2	11	1
1	3	4

respect to the type and number of vision symptoms and signs present before and after optometric vision therapy. Table 4 presents the number of patients manifesting one or more vision symptoms. Prior to therapy, the number of co-existing symptoms ranged from one to five, with most subjects presenting with two or three symptoms. After therapy, only six subjects reported persisting vision symptoms, with most having only one symptom. Table 5 presents a detailed profile for each of the symptoms. The most frequently occurring

symptoms were ocular motility difficulty when reading and diplopia (intermittent or constant); the least frequently reported symptoms were visual fatigue, movement of text on the page, and near task avoidance. As mentioned earlier, most symptoms were no longer present following therapy.

Table 6 presents the number of subjects manifesting one or more clinically significant signs. Prior to therapy, nearly all subjects presented with two or three signs. Following therapy, most signs had

Table 5.
Profile of vision symptoms in TBI patients (n=33, ages 40+ years)

Ocular motility difficulty when reading	Eyestrain	Diplopia	Visual fatigue	Head-aches	Blur	Sliding together of text words	Increased sensitivity to visual motion	Avoidance of near tasks	Number of patients pre-therapy	Number of patients post-therapy
X									2	1*
		X							1	0
X	X								9	1*
X		X							1	0
				X				X	1	0
X	X	X							1	0
X		X		X					8	2**
X				X	X				1	1*
X					X		X		1	0***
X	X	X	X						5	0
X	X			X		X			1	0
X	X	X			X				1	0
X	X			X	X		X		1	0

* ----minimal to no improvement in symptoms
 **---all symptoms lessened except for headaches
 ***- all symptoms lessened except for blur

Table 6.
Number of reported clinically significant vision signs in TBI patients (n=33; ages 40+ years)

Number of clinically significant vision signs	Pre-Therapy number of patients with signs	Post-Therapy number of patients with signs
3	12	1
2	15	1
1	6	1

Table 7.
Profile of clinically significant signs in TBI patients (n=33, ages 40+ years)

Abnormal DEM	Jerky eye movements	Receded near point of convergence	Restricted near base out ranges	Restricted fusional vergence ranges (far and near)	Suppression of binocular vision	Nausea during testing	Number of subjects pre-therapy	Number of subjects post-therapy
X							1	1*
X	X						2	1*
X		X					2	0
X		X	X				9	0
X		X		X			1	0
X		X			X		1	1*
X			X				2	0
X				X			2	0
X					X		1	0
					X	X	1	0
		X					1	0
		X	X				3	0
		X		X			4	0
		X	X	X			1	0

* ----minimal to no improvement in signs
 DEM= Developmental Eye Movement

normalized. Table 7 presents a detailed profile for each of the signs. The most frequent signs included abnormal Developmental Eye Movement Test (DEM)^a findings and a receded nearpoint of convergence, whereas the least frequent signs were jerky eye movements and nausea

during testing. As mentioned earlier, most signs normalized following VT.

QUESTION 3:
Can one improve reading ability, as assessed both subjectively and objectively, using simple oculomotor training protocols?

In this set of laboratory studies,²⁻⁵ a small group (n=9) of individuals with mild TBI were investigated in detail. All had symptoms and signs reflecting poor reading ability based on a detailed case history, as well as a five-item, symptom rating-scale questionnaire developed by us and used to assess such factors as reading comfort and

Table 8.
Reading results in subjects with TBI (n=9)

Parameter	Descriptor	Pre	Mid	Post
Symptom rating-scale questions	1. Ability to read comfortably*	1.33	2.75	3.67
	2. Ability to comprehend what was read*	1.94	3.00	3.11
	3. Ability to attend when reading when in a quiet room*	1.72	2.63	2.78
	4. Ability to attend when reading in a noisy room*	1.11	1.75	1.89
	5. Categorize your reading strategy*	1.78	2.33	3.61
Visagraph findings, Level 10	Words per minute*	183.2	164.4	189.2

* indicates p<0.05 from pre- to post-therapy ratings

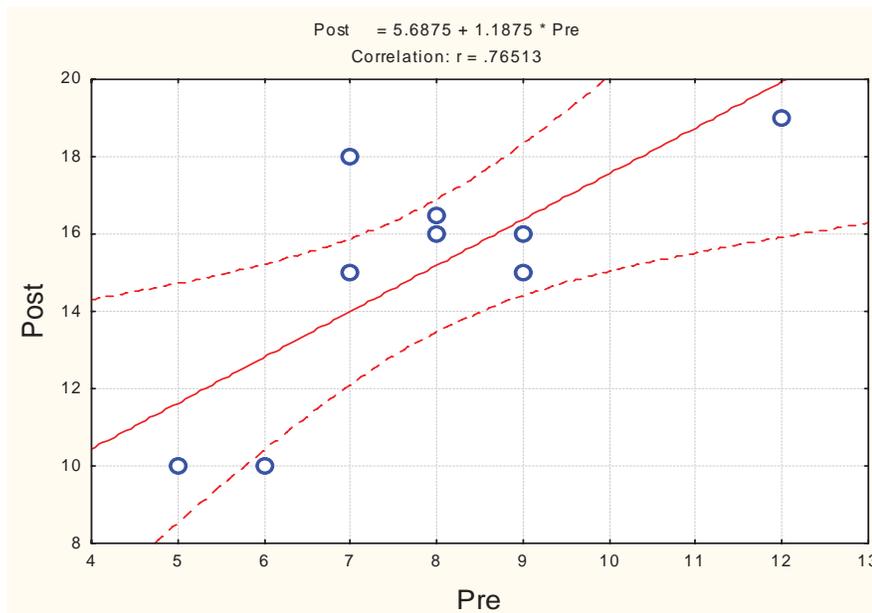


Figure 1: Overall score of symptom rating-scale questionnaire for each of the nine patients with mild TBI before (pre) and after (post) training. Each patient is represented by a circle.

attention.^{3,5} Subjects received a total of 9.6 hours of versional oculomotor training in the laboratory using a range of computer-controlled stimuli encompassing fixation, saccade, pursuit, and simulated reading protocols.³ Training was comprised of two 36 minute sessions each week for eight weeks. During four of the eight weeks, oculomotor auditory feedback related to eye position was added. This provided concurrent visual and auditory error-related information available with the potential for additional enhancement of performance.^{12, 13} There was no home training. All subjects were evaluated objectively in the above tasks before, mid-way, and immediately after completion of training, as well as at the three-month follow-up. They were also assessed subjectively using the five-item, symptom rating-scale questionnaire.^{3, 5} Overall, the questionnaire scores could range from a

low of 5 to a high of 24; the higher the score, the better was their subjective rating of reading ability. In addition, reading rate (words per minute) and reading eye movements were assessed objectively using the Visagraph reading eye movement system.¹⁴

Table 8 presents the key reading-related changes found subjectively and objectively. Both domains demonstrated significant improvement throughout. In all five areas probed subjectively, there were progressive and significant improvements in the group findings. Moreover, each individual exhibited a large subjective improvement ranging from approximately 160 to 260% (Figure 1), with a significant group correlation ($r=+0.76$). There was a small (~3%) but statistically significant improvement in reading rate as determined objectively. Thus, on average following the oculomotor training, they could now

read much longer and more comfortably in all environments with better attention and global reading strategy, along with a slightly higher reading rate. When the individual data were analyzed, reading rates had increased by 10-33% in five of the patients, but remained relatively constant at slightly abnormal to low normal levels in the other four.

An example of improvement in both reading eye movements and reading rate following training is presented in Figure 2. This patient's subjective questionnaire score doubled, and his objective reading rate in words per minute (wpm) increased by approximately 30% (pre: 137 wpm; post: 177 wpm; 250 wpm is normal). The patient executed considerably fewer progressive saccades during reading following the training, with a more consistent and regular overall oculomotor reading profile. Over the same test time interval, he read approximately three lines before training and five lines after training. The objectively assessed horizontal and vertical fixational, saccadic, simulated reading, and pursuit eye movements all exhibited significant improvements (i.e., increased accuracy) immediately following training.⁵ Furthermore, all of these training-related improvements were maintained at the three-month follow-up.

DISCUSSION

Patients with mild TBI are afflicted with an array of oculomotor-based problems that may negatively impact upon their reading ability.²⁻⁵ These include inaccurate saccades, inaccurate and highly variable fixation, and vergence dysfunction as were found in the present series of studies. These signs are consistent with one of their most frequent symptoms, namely "ocular motility difficulty when reading."¹⁰ Additionally, these signs and symptoms are consistent with the clinical and laboratory-based findings of our other related studies,²⁻⁵ as well as those reported by others.¹⁵

We were initially perplexed by the relatively small and objectively-based group mean increase in reading rate (3%). It occurred concurrent with the large, consistent, and significant improvements in subjectively-based, overall reading ability. It later became apparent that different aspects involved in reading were being assessed. Other components related to more global aspects of reading improved, namely reading duration, comfort, attention, and strategy. Hence, on average,

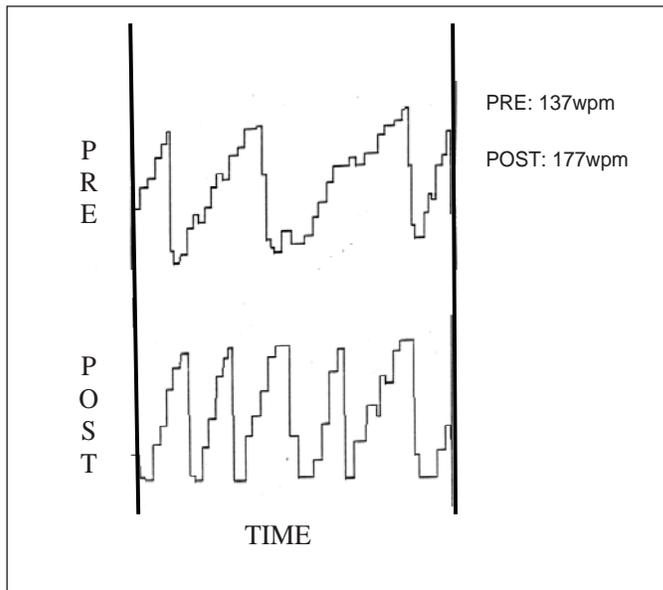


Figure 2: Horizontal reading eye movements in a patient with mild TBI before (pre) and after (post) training. Up is rightward, and down is leftward, in eye movement direction. Time periods are the same in both records.

subjects read either at nearly the same rate or slightly faster, but did so longer, and with greater ease, comfort, efficiency, and attention. The repetitive oculomotor conditioning lead to the development of a more structured and systematic approach to reading,¹⁶ as suggested by Zihl,^{17, 18} and as found in good readers.¹⁻⁶ This would reduce the oculomotor task “load” with resultant benefits to the cognitive and attentional areas of reading, as reflected in the positive reading rating-scale questionnaire changes found in the present study. No specific or purposeful attentional training¹⁹ was incorporated into the laboratory-based training program. While it may have been beneficial, it would have confounded interpretation of the basic experimental findings. One might speculate that the oculomotor training, by nature of its inherent intense and continuous feedback, strongly but indirectly involved the training of visual attention, and perhaps even more general aspects of attention itself. For example, subjects sat very still and quietly during the 36 minutes of actual training per session, with their full attention directed to the specific oculomotor task at hand. Every effort was made by the subject to perform optimally during these test periods, with the multiple levels of performance-related feedback continuously present (i.e., visual, verbal, and at times auditory). Thus, the training of attention per se appeared to be both an integral part, as well as a by-product, of the oculomotor rehabilitation protocol.

Future studies should include the formal assessment of attention concurrent with the oculomotor rehabilitation program to gain insight into this critical interaction. Furthermore, the formal training of attention per se may even be considered for likely rehabilitative enhancement. This notion should be extended to the clinical domain.

The global effects of the oculomotor rehabilitation may transfer to other activities of daily living. For example, some reported better concentration during conversations and improved visual scanning of the environment.²⁻⁵ It may also have an impact in another critical area, namely in facilitating other therapies that patients are either receiving concurrently or are intending to receive in the near future involving either reading or visual scanning.^{20,21} With improved reading skills, oculomotor control, increased reading comfort, and improved attention, other forms of therapy in which reading and eye movements play an integral role, such as speech therapy and cognitive therapy, may be enhanced.^{2-5, 11} For example, if one can only sustain reading for a few minutes in a cognitive therapy session, the full therapeutic benefit would not be attained.

Of interest was the apparent lack of an upper age limit for oculomotor remediation, with the successfully treated patients in both the clinic and laboratory studies ranging in age from approximately 30-70 years,²⁻⁵ and as was demonstrated in an earlier detailed case report.²² This is also

consistent with general oculomotor-based VT in the non-brain injured population,¹⁶ including the elderly.²³ This finding has an important human neurophysiological implication. It suggests the presence of considerable residual oculomotor plasticity, thereby allowing motor learning¹⁶ via conventional optometric VT¹⁶ to occur, even in an elderly brain manifesting frank and pervasive neural damage. In children and young adults, these positive training effects might be even more striking with their greater degree of neural plasticity. Overall reading ability and related eye movements improved significantly with training. This included the use of conventional oculomotor clinical VT paradigms,¹¹ as well as those specially-designed by us²⁻⁵ under laboratory computer control. These laboratory-based training paradigms could be easily modified for use in the clinic employing modern computer technology. For example, the target might be changed from a small spot of light, as used in the present studies, to a target with more intrinsic interest and attentional value, such as a constantly changing letter of the alphabet. The patient would not only be asked to foveate and/or track the target carefully, but in addition they would be requested to count the number of changes in the letter on the screen during the test period. And, if oculomotor auditory feedback were added,^{12,13} as was the case in our laboratory studies,²⁻⁵ the patient would additionally “hear” their eye movement errors, thus providing correlated and instantaneous visual and auditory information regarding accuracy of eye position, along with the heightened attentional and motivational aspects.²⁻⁵ In fact, most of the subjects performed better with the combined visual and auditory feedback, reporting that the immediate feedback was helpful. Thus, with such multi-modal oculomotor feedback information present, the improvements may approach optimality.¹³

Home training was purposely not incorporated into the laboratory-based oculomotor training program. While it would be predicted to have enhanced the training effects, there would have been no control with respect to performing each aspect of the procedures properly. Nor would timed elements necessarily be accurately followed, as required for a formal scientific investigation. Hence, it would have confounded interpretation of the experimental findings. However, in the standard clinic setting, home training should be

prescribed for daily reinforcement, especially under these more naturalistic viewing conditions.^{11,16} This was done in the clinically-based studies reported here.²⁻⁵ The overall findings of our studies are encouraging. In future studies, we plan to increase the sample size, expand the diagnostic categories, and widen the areas of investigation (e.g., attentional testing and vergence training). Furthermore, by incorporating brain imaging technology to assess neural changes produced by the optometric VT, we hope to develop an optimal oculomotor training protocol. In conclusion, using oculomotor-based training for a range of versional eye movement dysfunctions related to reading, individuals with acquired mild brain injury manifested improvements in reading ability as assessed both objectively and subjectively. We propose that optometric VT encompasses neuroplasticity via oculomotor learning, and perhaps indirectly via related attentional aspects.

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