

Article: Vision and Reading Deficits in Post-Concussion Patients: A Retrospective Analysis

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ABSTRACT

The prevalence of vision deficits in the pediatric/young adult concussion population in the private optometric practice setting remains unknown. Thus, a retrospective chart review in this area was conducted in the practice of the first author. Twenty-five consecutive patients with a medical diagnosis of concussion received a comprehensive vision and ocular health examination, which also included an objectively-based Visagraph reading assessment and clinical vergence/accommodative facility testing. Three primary categories of oculomotor-based deficits were found: convergence insufficiency (56%), accommodative insufficiency (76%), and oculomotor-based reading dysfunctions (68-82%).

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The most common symptom was headaches (84%), with 25% of the symptoms related to reading. 68% (15/22) were categorized as reading at least 2 grade levels below their current school grade level for reading eye movements based on the Visagraph findings. These overall findings are consistent with the general oculomotor-based/reading findings in the concussion/mTBI literature. The present results have important practical ramifications regarding the importance of pre-concussion baseline oculomotor and Visagraph testing, as well as post-concussion follow-up testing, to help assess a student's ability to return-to-learn (RTL).

INTRODUCTION

The topic of concussion/mild traumatic brain injury (mTBI) has come to the forefront of the clinical vision world due to the constellation of visual problems/visual dysfunctions secondary to sports-related concussions/head injuries,^{1,2} and also the recent war efforts.³ Vision problems are present in thousands of our soldiers and are likely in a similarly large but unknown number of athletes, especially in contact sports such as football, boxing, and soccer. However, the most common etiologies of a concussion are the result of motor vehicle accidents, assaults, and falls.^{4,5} Together, they represent a relatively large and important segment of patients examined by the contemporary neuro-rehabilitative optometrist.

A concussion/mTBI results in a constellation of general sensory, motor, perceptual, linguistic, behavioral, cognitive, and psychological deficits.^{4,5} For example, an individual may report general headaches/migraines, short-term memory problems, muscle stiffness and spasms, chronic fatigue, and impulse control issues. More specific to the present paper, they can manifest a wide array of visual problems, such as blur, intermittent diplopia, oculomotor-based reading difficulties, and impaired visual memory, to name a few.⁴⁻⁶ Presence of such visual deficits can have an adverse impact on an individual's vocational and avocational goals, as well as negatively affect the general rehabilitative process.^{7,8} For example, impaired saccadic scanning and poor visual discrimination skills can hinder progress in cognitive rehabilitation-based visual search tasks incorporating a complex array of finely-detailed targets.^{7,8}

Over the past decade, there have been a number of clinical studies focusing on the visual deficits found in the concussed/mTBI patient in hospital^{9,10} and academic¹¹⁻¹⁴ settings. In all cases, the prevalence of visual deficits, in particular those that are oculomotor based, has been well documented. Deficits of the vergence (e.g., convergence insufficiency), accommodative (e.g., accommodative insufficiency), and/or versional (e.g., saccadic inaccuracy) systems,

with reading problems (e.g., skipping lines, rereading) being the primary symptom both in non-blast and blast-related concussion/mTBI cases.¹⁵ These findings suggest generality and pervasiveness of the traumatic event and correlated visual problems. For example, Ciuffreda et al.¹⁶ determined the frequency of occurrence of oculomotor dysfunctions encompassing vergence, accommodation, version, strabismus, and cranial nerve palsy in 160 individuals with mTBI and reporting visual symptoms. Vergence system abnormality was the most common dysfunction: 56.3% of the population had one or more vergence-related abnormalities, with convergence insufficiency being most common (42.5%). In addition, 51.3% of the population manifested one or more versional dysfunctions, with saccadic deficits (e.g., saccadic dysmetria) being the most common anomaly. Among those who were below 40 years of age (51 out of the 160 subjects), 41.1% exhibited an accommodative dysfunction, with accommodative insufficiency (AI) being the most common problem. Strabismus in the form of constant/intermittent deviations was present in 25.6% of the population.

In contrast, there has been a paucity of such studies that are based on the findings in the optometric clinical practice setting. To the best of our knowledge, the only one similar in setting to the current study was that of Hellerstein et al,¹⁷ where adults (mean age 39 years) were assessed in her optometric practice. They tested 16 individuals with medically-diagnosed mTBI and compared them with 16 visually-normal, age-matched control subjects. A battery of clinical tests was performed with an emphasis on those that were binocular/oculomotor in nature. There were several significant differences ($p < 0.05$) in the binocular/oculomotor clinical measures between the mTBI and control groups. The following findings were abnormal in the mTBI group: near point of convergence break and recovery, base-in vergence break and recovery at distance and near, base-out vergence recovery at distance, near cover test, pursuit

tracking, and stereopsis; vertical phoria at near exhibited a trend ($p=0.058$). Furthermore, there were several significant differences ($p<0.05$) in symptoms between the two groups: blur, diplopia, and reading problems were much more frequent in the mTBI group. Hence, as found in other non-practice-based settings as described earlier, binocular/oculomotor clinical signs and related symptoms are more prevalent in the mTBI population.

The purpose of the present optometric, clinical practice-based, record review was to extend the study of Hellerstein et al¹⁷ in children and young adults, with inclusion of objectively-based Visagraph assessment of reading ability, as well as dynamic facility assessment of vergence and accommodation.

METHODS

The clinical records of the consecutive patients referred with a medical diagnosis of concussion were reviewed from October 2011 through October 2012. These were all patients who were referred from physicians who specialized in concussion management. Excluded from the chart review were any patients with strabismus, amblyopia, ocular disease, developmental disabilities (such as autism spectrum disorder), neurologic disease, or psychiatric disorders which did not exist prior to the first concussion.

Twenty five patients met the criteria for chart review. Two of these patients had a prior diagnosis of reading disability; they were included in the binocular/accommodative analysis, but excluded from the Visagraph reading eye movement analysis.

Patient's ages ranged from 12 years to 31 years, with a mean of 17.1 years. There were 14 males and 11 females. Their last concussion was diagnosed from 1-35 months prior to the vision examination/consultation, with the average time being 5.2 months from last concussion to evaluation.

Table 1 presents a summary of the tests performed on the concussion/mTBI patients. Included were those used in the basic refractive

Table 1: Visual tests included in analysis.

Symbols: pd=prism diopters, D=diopters, cm=centimeters, and sec arc=seconds of arc

Clinical test
Near cover test (pd)
NPC break (cm)
NPC recovery (cm)
NRA (D)
PRA (D)
Monocular accommodative facility (cpm)
Minus lens amplitude of accommodation (D)
Near base in blur/break/recovery (pd)
Near base out blur/break/recovery (pd)
Distance base in break/recovery (pd)
Distance base out blur/break/recovery (pd)
Vergence facility (cpm)
Stereopsis (sec arc)
Visagraph (Reading rate and grade level efficiency)

assessment,¹⁸ as well as those typically performed in the specialty oculomotor/binocular-vision-based evaluation.¹⁸ They were performed per standard clinical guidelines/protocols.^{18,19} All testing was conducted with the patient's habitual distance spectacle correction in place, unless the new distance refraction indicated a change, or a near prescription was deemed appropriate. Some additional details include: distance and near phorias were assessed using the alternate cover test; the near point of convergence was measured with both an accommodative (20/30 letter at near,¹⁸) and a non-accommodative target (penlight)²⁰ each taken three times, with the most reduced value recorded; distance and near horizontal vergence ranges; negative and positive relative accommodation; and amplitude of accommodation (minus lens technique); all were assessed in the phoropter. Accommodative facility was tested using +/-2.00D lens flippers, whereas vergence facility was assessed using 12 base-out (BO)/3 base-in (BI) prism. Stereopsis was assessed using a Randot Test. Lastly, the Visagraph was used to assess reading eye movement efficiency.²¹ Two paragraphs were tested, with each being one grade level below the independent reading level.²² Then, a third

Table 2: Vergence, accommodative, and reading deficits by percent (%) occurrence

Diagnosis	Percent Occurrence
Convergence Insufficiency Near point of convergence of ≥ 6 cm break and - Reduced positive fusional convergence at near (< 20 pd or fails Sheard's criterion) or - Vergence facility (distance or near) ≤ 9 cpm with more difficulty with base-out ¹	56%
Convergence Excess ≥ 3 pd esophoria at near and - Reduced negative fusional convergence at near (< 8 pd or fails Sheard's criterion) or - Vergence facility at near ≤ 9 cpm with difficulty with base-in ¹	8%
Accommodative Insufficiency Amplitude of accommodation ≥ 2 diopters below mean for age (15-1/4 age) or Monocular accommodative facility ≤ 6 cpm (difficulty with minus lenses) ¹	76%
Reduced Reading Rate ²	82%
Reduced Reading Efficiency ²	68%

1. Adapted from Master et al¹⁰

2. Based on a Visagraph grade-level equivalent of 2 or more grades below their actual grade level

Table 3: Primary symptoms in order of frequency reported.

Headache (21)
Light sensitivity (13)
Skip/lose place (13)
Blur (12)
Visual motion sensitivity (11)
Decreased reading comprehension (10)
Eyestrain (9)
Near diplopia (8)
Dizziness/nausea (7)
Decreased concentration (6)
Decreased balance (6)
Visual fatigue (5)
Decreased reading speed (4)
Words running together when reading (4)
Distance diplopia (2)
Poor depth perception (2)

paragraph, 5 grade levels below the independent reading level, was tested. This dual-level of testing differentiated between a linguistic versus oculomotor basis for the reading deficit. Lastly, if the individual could not obtain a 70%

or better comprehension level on a given test paragraph, the grade level was reduced further, until they could attain this criterion. Due to the fact that this was a chart review, some clinical and Visagraph tests were missing. Hence, the actual number tested is specified in the tables out of a possible 25 patients.

Due to the number of variables assessed in this study, the standard t-test analysis would produce a greater potential for false positive errors. Thus, to correct for this likely problem, a more rigorous test/criterion was used, namely the Holms method.²³ Hence, effectively a more stringent alpha level was calculated to characterize each of the variables tested as being 'statistically significant' ($p < 0.05$).

RESULTS

The 3 primary oculomotor/binocular diagnoses and their percentages are presented in Table 2. These included vergence dysfunction (64%), accommodative insufficiency (76%), and oculomotor-based reading dysfunctions (68% had reduced reading efficiency and 82% had reduced reading speed). The diagnosis of convergence excess was 8%. 92% of the patients had more than one such diagnosis.

The primary symptoms are presented in Table 3 in order of the frequency reported out of the 25 patients. These were assessed through case history and as reported on a symptom questionnaire that is used in the primary author's private practice (Table 4). Only symptoms that were checked off as occurring "sometimes," "usually", or "always" were reported in Table 3. The most frequent symptom was headache (84%), whereas the least reported symptoms were distance diplopia and poor depth perception (8%). Four of the 16 symptoms (25%) related to reading at near (skipping or loss of place, decreased reading comprehension, decreased reading speed, and words running together when reading.)

Table 5 presents the vision findings for the mTBI group as compared to Morgan's normative data.²⁴ There were several significant differences.

Table 4: Symptom checklist used in the primary author's private practice for patients with a history of ABI.

Please consider each symptom and place a check in the box: 1 if never present, 2 rarely present, 3 sometimes present, 4 usually present, 5 always present

	NEVER	RARELY	SOMETIMES	USUALLY	ALWAYS
SYMPTOM	1	2	3	4	5
Difficulty moving or turning eyes					
Pain with movement of the eyes					
Pain in or around eyes					
Wandering eye					
Double vision					
Blurred vision, distance viewing					
Blurred vision, near viewing					
Slow to shift focus from far to near					
Difficulty taking notes					
Pulling or tugging sensation around eyes					
Face or head turn					
Head tilt					
Covering or closing one eye					
Disorientation					
Bothered by movement around you					
Bothered by noises in environment					
Light sensitivity					
Discomfort while reading					
Unable to sustain near work/reading for adequate periods					
General fatigue while reading					
Loss of place while reading					
Eyes get tired while reading					
Headaches					
Easily distracted					
Decreased attention span					
Reduced concentration ability					
Difficulty remembering what has been read					
Loss of balance					
Poor handwriting					
Poor posture					
Dizziness					
Poor coordination/eye hand coordination					
Clumsiness					

Eight out of the 13 clinical tests (62%) were significantly different, i.e., abnormal when compared to the normative data.

Table 6 compares two components of the Visagraph-based findings, which were found to be statistically different ($p < 0.05$) than grade-level

Table 5: Statistically significant findings compared with Morgan's normative values²³ ($p < 0.05$).

Test	N	Morgan's Normative Data (mean value)	Present Findings (mean value)
Near cover test (pd)	25	3 exophoria	6 exophoria
NPC break (cm)	24	5.00	12.81
NPC recovery (cm)	24	7.00	19.37
PRA (D)	21	- 2.37	-1.51
Distance BO recovery (pd)	20	10.00	5.90
Near BI recovery (pd)	25	13.00	10.72
Accommodative amplitude	21	10.53*	6.37
Vergence facility (cpm)	24	15.00**	10.42

* Expected mean accommodative amplitude by age of patient (minus lens method)

**Vergence facility based on a norm of 15cycles/minute¹⁸
Symbols: pd =prism diopters, D=diopters, cm=centimeters

Table 6: Statistically significant ($p < 0.05$) measures of Visagraph recordings (n=22)

	Actual Grade Level	Visagraph Reading Rate (grade level equivalent)	Visagraph Grade Level Efficiency*
Mean	10.1	5.6	6.0
Standard Deviation	1.8	3.8	4.0

*Grade level norms of relative efficiency. (Relative efficiency= rate (wpm)/ fixations per 100 words + regressions per 100 words)²¹

normative data,²⁵ namely reading rate and grade level efficiency. The subject's actual mean school-grade level was 10.1, whereas the measured reading speed was grade level 5.²⁵ based on the Visagraph norms, a 45% difference. Similarly, reading grade-level efficiency was 6.0 based on the Visagraph norms, a 40% difference. 68% (15/22) had reading efficiency at least 2 grade levels below their current school grade level, and 82% (18/22) had reading speed at least 2 grade levels below their current school level, based on the Visagraph findings.

DISCUSSION

The results of the present study have several new and important clinical implications. It is the first optometric, office-based study investigating the prevalence of these three main oculomotor-based visual diagnoses in the pediatric and

young-adult population, with all patients having a medically-based diagnosis of concussion. It is also the first in this same population and setting to have the objectively-based Visagraph reading eye movement findings analyzed and compared to grade level norms. The objective reading test results revealed a high prevalence of reduced reading speed and efficiency. It has been reported²⁶ that it is common to have cognitive difficulties, such as learning new tasks or remembering previously learned material, after concussion. Add to this the possibility of reduced reading speed and efficiency, and the likelihood of successful return-to-learn (RTL) becomes even more daunting. Furthermore, the high prevalence of these visual problems suggests the need for a comprehensive optometric visual evaluation in post-concussion patients. The results also indicate the need for visual intervention to reduce their symptoms and improve visual function. Treatment may include lenses, prisms, tints, and partial occlusion, as well as concurrent, longer term interventions, such as vision therapy, which has been demonstrated to be highly effective in the adult, concussion/mTBI population.^{11-15,27}

The present results are consistent with a recent hospital-based study of Master et al¹⁰ in the pediatric population (n=100; ages 11-17 years, mean=14.5 years), with a diagnosis of concussion ranging from less than one month to more than three months after their injury. Those of more recent-onset concussion were more likely to manifest a visual diagnosis. Overall, they found that nearly 70% of their adolescent population had associated abnormal oculomotor findings. In addition, there were related visual diagnoses and symptoms, namely convergence insufficiency (49%), accommodative insufficiency/infacility (51%), and saccadic dysfunction (29%), which is similar in frequency and diagnostic category to the present study. Also, many had more than one of these three clinical oculomotor diagnoses in both studies. This is consistent with an earlier retrospective investigation performed in a clinical, academic

setting in adults (n=160) with visual symptoms and a diagnosis of mTBI.¹⁶ The present findings are also similar to the only other optometric, practice-based study, but again this was in an adult concussion/mTBI population,¹⁷ as described earlier. Lastly, our results are in agreement with a host of other studies in the adult population with concussion/mTBI, both in clinical^{10,28} and academic/laboratory^{11-15,29} settings, with patients primarily being in the chronic phase of the brain insult several months to years later. Thus, there is evidence across a wide range of ages and test settings for the high prevalence and persistence of symptomatic oculomotor deficits, in the concussion/mTBI population.

The Visagraph findings lend a new and important dimension. Such objective testing of reading ability/reading efficiency has never been performed in a pediatric/young-adult, optometric, clinic practice-based population having a medically-based concussion diagnosis. Objective findings are convincing in terms of determining/demonstrating quantitatively the effects of an oculomotor-based visual dysfunction, such as saccadic dysmetria/inaccuracy^{12,29} on such a universal and naturalistic task, namely reading. In those with the diagnosis of concussion/mTBI, and persistent visual symptoms, oculomotor-based "reading problems" are the most common symptom.^{11-15,28} One cannot function efficiently in the modern world with such a debilitating visual problem. Furthermore, presence of basic oculomotor/visual scanning problems will have an adverse impact on other forms of testing and/or remediation, such as cognitive testing/training incorporating visual scanning and/or fine discrimination tasks.^{7,8}

There were some potential limitations to the present study. First, it was a retrospectively-based and not a prospectively-based investigation. Second, the sample size was relatively small. Third, it was a skewed population; that is, all patients came to a neuro-optometric rehabilitative practice for a comprehensive vision assessment, as they were all medically-diagnosed as having a concussion with related visual

symptoms. Furthermore, they were specifically referred to the first author's private optometric practice because of his experience in working with this population. Lastly, an informative but non-validated symptom survey was used, (Table 4) rather than a validated one, as there is no validated symptom survey for concussion/mTBI patients at this time.

There are some important directions for future investigations. First, a more powerful and larger prospectively-based study in the optometric practice setting should be conducted in the pediatric and young-adult populations in those with medically-diagnosed concussion/mTBI, especially for those active in sports where return-to-play (RTP) is frequently a key consideration,¹ as well as educationally for return-to-learn (RTL).²⁶ Second, formal, conventional reading tests, such as the Wide Range Achievement Test (WRAT4),³⁰ could be incorporated in conjunction with the objectively-based Visagraph reading testing, along with the binocular/oculomotor clinical testing. Third, the effect of vision therapy should be assessed in this population. Recent retrospective and prospective studies have demonstrated rapid, efficacious, and positive results with oculomotor therapy in the mTBI adult population.^{11-14,27,31,32} Larger clinical trials would be very helpful to establish the most effective treatment protocols. Lastly, some simple temporal processing tests should be incorporated to assess more subtle and demanding aspects of visual performance, such as critical flicker frequency (CFF)^{33,34} and coherent motion,³⁵ in this vulnerable population.

In conclusion, there were several vision and reading related deficits that were found in this retrospective study of post-concussion patients. Specifically, the accommodative and vergence dysfunctions were in agreement with earlier studies in academic/clinical centers, as well as those conducted with military personnel. The objective Visagraph recordings, which showed reduction of reading speed and efficiency, are new findings. Together, these findings can be used to help develop visual guidelines to for RTL

in post-concussion school-aged children and young adults.

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