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# Vision Diagnoses Are Common After Concussion in Adolescents

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## Abstract

*Objective*. To determine the prevalence of vision diagnoses after concussion in adolescents. *Methods*. Cross-sectional study from July 1, 2013 to February 28, 2014, of patients aged 11 to 17 years with concussion evaluated in a comprehensive concussion program. *Results*. A total of 100 adolescents were examined, with a mean age of 14.5 years. Overall, 69% had one or more of the following vision diagnoses: accommodative disorders (51%), convergence insufficiency (49%), and saccadic dysfunction (29%). In all, 46% of patients had more than one vision diagnosis. *Conclusions*. A high prevalence of vision diagnoses (accommodative, binocular convergence, and saccadic eye movement disorders) was found in this sample of adolescents with concussion, with some manifesting more than one vision diagnosis. These data indicate that a comprehensive visual examination may be helpful in the evaluation of a subset of adolescents with concussion. Academic accommodations for students with concussion returning to the classroom setting should account for these vision diagnoses.

### Keywords

concussion, mild traumatic brain injury, convergence insufficiency

## Background

Up to 3.6 million concussions occur annually, as estimated by the Centers for Disease Control and Prevention, and this likely represents an underestimate of the clinical problem.[1,2] Approximately 65% of these injuries occur in the pediatric and adolescent population, 5 to 18 years of age, with the 11- to 14- and 15- to 18-year-old age groups representing the largest proportion of those injured.[3,4] There are increasing concerns that children may be particularly vulnerable to the consequences of concussion and may have more prolonged and complicated outcomes from a cognitive and developmental perspective.[5-9]

Common problems in concussion that are observed in both the adult and pediatric populations include physical signs and symptoms (headache, dizziness, nausea, balance problems, fatigue, light and noise sensitivity, sleep problems), cognitive deficits (memory, attention, executive functioning, reaction time), and emotional issues (irritability, sadness, nervousness, anxiety and depression).[10,11] In particular, concussion-related visual complaints, including blurred or double vision, eye fatigue, the appearance of words moving on the page, loss of place when reading, and difficulty sustaining attention on a visual task have been reported in the adult population.[12-14] While significant deficits in binocular vision (convergence), accommodative (focusing) and saccadic (eye movement) disorders have been reported in adults with concussion in both the civilian and military populations with a prevalence of up to 30% to 42%,[15-21] the prevalence of visual diagnoses in adolescents with concussion is unknown. The adolescent population may be at significant risk for morbidity due to such concussion-related vision disorders because of the amount of reading and visual work involved with

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full-time schoolwork.[22-24] A recent study using a brief Vestibular/Ocular Motor Screening Assessment (VOMS) tool that clinically assesses saccades, smooth pursuits and convergence, showed that VOMS accurately distinguished concussed patients who had symptoms of oculomotor impairment from uninjured controls, aged 9 to 18 years.[25] This study indicates that further investigation into the prevalence of vision diagnoses following concussion is warranted.

Reading is a complex higher order integrative function, which requires adequate accommodative, vergence, and saccadic response at the initial stage of gathering visual information. These processes are necessary to initiate and sustain visual function during reading.[24] Areas of the brain involved in these complex tasks include the dorsolateral prefrontal cortex (DLPC), the posterior parietal cortex, and frontal and supplemental eye fields, as well as the brainstem and cerebellum. Each of these regions can be affected by concussion injury.[14,26] The DLPC plays a significant role in attention and working memory while also interacting with multiple other regions of the brain in carrying out tasks of executive function. In addition, from an oculomotor perspective, saccadic function and vergence are also among the many tasks influenced by the DLPC. Injury to this area may result in oculomotor deficits after concussion, which may negatively affect the task of reading, and thereby, learning in adolescents. Such deficits affecting reading have been reported in adults following concussion.[12-21] Due to the high visual work load of adolescents in school, identifying such deficits after concussion is imperative in order to properly direct their postinjury management in school, which is their occupational setting.

The objective of this study was to use comprehensive vision testing to determine the prevalence of vision diagnoses in adolescents aged 11 to 17 years presenting to an outpatient specialty concussion program for evaluation and treatment of concussion. Secondary objectives were to determine if a symptom questionnaire, the Convergence Insufficiency Symptom Survey (CISS),[27,28] is useful in identifying adolescent patients with vision diagnoses after concussion. The CISS was not originally designed as a screening tool for convergence insufficiency; rather, it was intended for use in clinical trials to assess change in symptoms as an outcome after treatment for convergence insufficiency. We sought to evaluate the utility of the CISS as a screening tool for visual complaints in the setting of concussion as compared with the Post Concussion Symptom Scale (PCSS), which is a validated 22-point symptom questionnaire administered independently or as part of computerized neurocognitive testing.[11] An additional secondary objective was to identify any associations between visual diagnoses and changes in computerized neurocognitive testing scores after injury.

## Methods

We conducted a single-center, cross-sectional study of patients who presented to the Minds Matter Concussion Program at The Children's Hospital of Philadelphia. All patients who presented for clinical care between July 1, 2013 and February 28, 2014 were eligible for the study. Our institutional review board approved this study prior to the commencement of subject enrollment and data collection. Study participants were enrolled by trained research assistants during their office visit after parental informed consent and child assent was obtained. We included patients with the medical diagnosis of concussion who were 11 to 17 years old at the time of enrollment. We excluded those who were unable to participate in vision testing for any reason, did not have corrected 20/30 visual acuity, or had a preexisting history of strabismus, amblyopia, surgery, patching, or vision therapy.

A diagnosis of concussion was based on the history of any direct or indirect force transmitted to the head resulting in the temporally-associated onset of signs or symptoms of concussion as defined by the Consensus Statement on Concussion in Sport.[11] Vision diagnoses were made based on objective criteria obtained in vision testing as described in Table 1.[29] Computerized neurocognitive testing using Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), which includes the PCSS questionnaire, was performed as part of the routine clinical evaluation of the patient for concussion.[30,31]

Standardized historical and physical examination data,[32] as well as computerized neurocognitive testing results with ImPACT, were abstracted from the electronic medical record into Research Electronic Data Capture (REDCap) for analysis. As part of the study, the Convergence Insufficiency Symptom Survey (CISS), a validated questionnaire for the assessment of change in visual symptoms after treatment for convergence insufficiency, was administered to all participants. This tool has been used as an outcome measure in several randomized clinical trials studying the treatment of convergence insufficiency. It is a 15-question instrument with Likert-type scale responses and the expected score for a normal child aged 11 to 17 years is <16.[27,28] A standardized, comprehensive vision examination, including administration of the CISS, separate from the routine clinical assessment for concussion, was performed by either a developmental optometrist or trained research

**Table 1.** Diagnostic Criteria for Binocular Vision, Accommodative, and Eye Movement Diagnoses.

| |
|---|
| *Convergence insufficiency* |
| Requires: 1 |
| Plus at least 1 finding from 2-4 |
| Near point of convergence of ≥6 cm break |
| Exophoria at near at least 4 pd greater than at distance |
| Reduced positive fusional convergence at near (<20 pd or fails Sheard's criterion[a]) |
| Vergence facility (distance or near) ≤9 cpm with difficulty with base-out |
| *Convergence excess* |
| Requires: 1 |
| Plus at least 1 finding from 2-3 |
| ≥3 pd esophoria at near |
| Reduced negative fusional convergence at near (<8 pd or fails Sheard's criterion[a]) |
| Vergence facility (distance or near) ≤9 cpm with difficulty with base-in |
| *Accommodative insufficiency* |
| Requires: 1 or 2 |
| Amplitude of accommodation ≥2 diopters below mean for age (15-1/4 age) |
| Monocular accommodative facility ≤6 cpm (difficulty with minus lenses) |
| *Saccadic dysfunction* |
| Requires: 1 or 2 |
| Developmental Eye Movement Test ratio score: 1 SD or more below the mean |
| Developmental Eye Movement Test error score: 1 SD or more below the mean |

Abbreviations: pd, prism diopters; cpm; cycles per minute; SD, standard deviation.
[a]Failing Sheard's criterion = positive fusional vergence is less than twice the near phoria.

assistants. This evaluation included an assessment of visual acuity, eye alignment (Modified Thorington Test), fusional vergence (Step Vergence Test and Vergence Facility Test), convergence (Near Point of Convergence Test), accommodative amplitude and accommodative facility (Push-up Test and +2/−2 test) and eye movements (Developmental Eye Movement Test)[29] (Table 1).

Descriptive statistics were calculated for the outcome measures. Fisher's exact test was used for 2-way categorical comparisons of count data. Mann-Whitney analysis for nonparametric data was performed to determine the relationship between neurocognitive test scores and vision diagnoses. All significance levels were set at $P < .05$. Statistical analysis was performed using R version 3.0.3.[32] Bootstrap 95% confidence intervals (CIs) were estimated using the boot package.[34,35] Prevalence ratios (PRs) and 95% CIs were calculated using the epiR package.[36]

## Results

One hundred participants were enrolled during the study period. The mean age was 14.5 years (age range 13.5-14.8 years). Of the study subjects, 42% were male and 65% sustained their concussion as the result of sports participation, while the remainder sustained their concussions in nonsports activities such as falls. Among the enrolled subjects, 29% were seen within 1 month of their injury, 26% were evaluated between 1 and 3 months after their injury, and 45% were seen >3 months after their injury. Patients seen within 1 month of injury were more likely to have a vision diagnosis than those evaluated greater than 3 months after injury. Patients who were evaluated early after injury (within 30 days) were more likely to have a vision diagnosis than those evaluated later after injury (>90 days) ($P$ = .03, PR = 1.41; 95% CI = 1.04-1.92). A total of 32% of subjects had a history of prior concussion, which was not associated with an increased risk of vision problems after concussion ($P$ = .36).

The primary objective of this study was to determine the prevalence of vision diagnoses after concussion in an adolescent population age 11 to 17 years. Overall, 69% of enrolled subjects had at least one vision diagnosis after concussion, with 51% presenting with accommodative insufficiency or infacility, 49% with convergence insufficiency, and 29% with saccadic dysfunction. Of note, a substantial number of subjects had more than one vision diagnosis following concussion: 22% of patients with convergence insufficiency also had accommodation deficits, while 14% of those with both convergence insufficiency and accommodation deficits also had saccadic dysfunction on exam simultaneously (Figure 1).

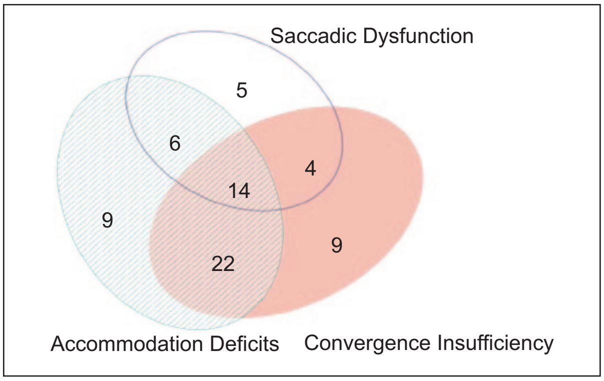


**Figure 1.** Vision diagnoses after concussion.

**Table 2.** Association of Convergence Insufficiency Symptom Score (CISS) With Vision Diagnosis.

| Vision Diagnosis | CISS <16 | CISS ≥16 |
|---|---|---|
| (−) Any vision diagnosis | 19 | 12 |
| (+) Any vision diagnosis | 15 | 54 |
| | | *P* = .0002 |
| (−) Convergence insufficiency | 24 | 27 |
| (+) Convergence insufficiency | 10 | 39 |
| | | *P* = .006 |
| (−) Accommodative dysfunction | 23 | 27 |
| (+) Accommodative dysfunction | 11 | 39 |
| | | *P* = .02 |

A score of ≥16 on the CISS indicates that the patient may be symptomatic from convergence insufficiency. A secondary objective of this study was to determine if the CISS could be useful as a screening tool for identifying vision diagnoses in concussion as compared with the widely used PCSS. Among our study subjects, only 29% of patients specifically reported vision problems on the PCSS. In our study, the mean CISS score was 19.8 for all study participants. Overall, the mean CISS score was 22.9 for those with a vision diagnosis, as compared to a score of 13.0 in those without any vision diagnoses (Mann-Whitney $P <$ .001), and a high CISS score of ≥16 was strongly associated with a vision diagnosis ($P < .001$, PR = 1.85; 95% CI = 1.25-2.75). (Table 2.) More specifically, a CISS score of ≥16 was highly correlated with the diagnosis of convergence insufficiency ($P = .006$, PR = 2.01; 95% CI = 1.15-3.51) and accommodative dysfunction ($P = .02$, PR = 1.83; 95% CI = 1.08-3.09). In contrast, a high CISS score of ≥16 was not associated with the presence of saccadic dysfunction ($P = .25$) (Table 2).

Another secondary objective of this study was to determine if there was any relationship between vision diagnoses after concussion and scores on computerized neurocognitive testing. Specifically, we examined the relationship between the presence of a visual diagnosis and test-derived verbal memory composite score, visual memory composite score, visual motor speed composite score, reaction time, and impulse control (Table 3). Poor verbal memory composite scores ($P = .002$) and visual motor speed scores ($P = .005$) were significantly correlated with the presence of a vision diagnosis.

## Discussion

Vision problems are very common in adults following concussion,[12-21] and vision complaints have been described in the adolescent population with concussion.[25] We found that a substantial proportion of adolescents in our clinical population with concussion have visual diagnoses identifiable with a comprehensive vision assessment beyond visual acuity.[29] Our findings indicate a much higher prevalence of vision diagnoses in adolescents with concussion, as compared with reported prevalence rates in the general pediatric population without concussion. The prevalence of convergence insufficiency in children has been reported between 2% and 8% and the prevalence of accommodative dysfunction has been reported as 5% in the general population, as compared with 49% and 50%, respectively, in our study of adolescents with concussion.[37-39] While our study excluded patients with binocular vision disorders, it is possible that undiagnosed binocular vision problems comprise a portion of our patients with binocular vision problems following concussion. Despite this limitation, it is unlikely that undiagnosed preexisting binocular issues account for the notable difference observed between the prevalence of convergence insufficiency in our cohort with concussion as compared with the reported prevalence in the general population.

Oculomotor functioning is supported by the occipital lobe, brainstem, frontal lobe, parietal lobe, and cerebellum, with significant integration between these areas and the language areas of the brain to support reading.[14,26] Because of the diffuse nature of concussion injury, both specific areas of the brain, as well as the integrative pathways needed for accurate and automatic oculomotor functioning, may be affected. The high prevalence of vision diagnoses after concussion reflects the widespread neural architecture involved in visual processing, which may make the visual oculomotor system particularly susceptible to the diffuse stretch injury seen in concussion.

**Table 3.** Relationship Between Neurocognitive Test Scores and Vision Diagnoses.

| | (−)Vision Diagnosis | (+)Vision Diagnosis | *P* |
|---|---|---|---|
| Verbal memory composite score | 88.4 | 76.9 | .002 |
| Visual memory composite score | 75.8 | 68.0 | .66 |
| Visual motor speed composite score | 37.6 | 32.0 | .005 |
| Reaction time | 0.58 | 0.66 | 1 |
| Impulse control | 6.8 | 7.8 | .88 |

Identification of concussion-related vision diagnoses is important because of the extensive visual demands of adolescents engaged in full-time school. In today's modern classroom, the use of technology is widespread and these electronic interfaces may add an additional level of visual demand when recovering from a concussion. The high prevalence of vision diagnoses following concussion in this study highlights the importance of implementing appropriate academic accommodations for students returning to the classroom.[22,23] Since accommodative, binocular vision, and eye movement problems can cause significant symptoms related to visual activities,[27] it is important for physicians to suggest specific school-based accommodations to optimally manage these vision-related symptoms. Strategies that include frequent visual breaks, oral teaching, audiobooks, large-font printed material (vs. small font electronically displayed material), or preprinted notes may be extremely helpful to a student returning to learn after a concussion.[22,23]

The PCSS is a widely used tool for diagnosis of concussion and for monitoring recovery over time.[31] In our study population, fewer than one-third of the study subjects reported visual symptoms using this scale. In comparison, the CISS is a validated 15-point questionnaire developed as a tool to monitor changes in symptoms after treatment for convergence insufficiency.[27,28,39] In our study, the CISS identified patients with vision diagnoses following concussion, and shows promise as a potential screening tool for vision diagnoses following concussion.

For the general pediatrician, the CISS may prove to be a highly cost-effective means of identifying patients with concussion-related vision deficits who might benefit from referral to a concussion specialist or an eye care professional for a comprehensive visual and oculomotor evaluation beyond visual acuity testing and for possible treatment of accommodation, binocular vision, and eye movements. Future studies to determine potential cutoff scores for the CISS in identifying vision diagnoses after concussion would be helpful.

Computerized neurocognitive testing with tools such as ImPACT are commonly used to aid in the diagnosis and management of acute concussions. In our study, vision disturbances were correlated with poorer composite scores on visual motor speed, which might be expected in disorders of vision. In addition, vision diagnoses were also associated with poorer verbal memory composite scores, which may reflect the role of the DLPC in both working memory and oculomotor function. This correlation may be due to multiple factors, including the visual nature of the computerized neurocognitive test, as well as the overlapping function of the DLPC in executive function, memory, and oculomotor visual function. The fact that computerized neurocognitive testing, in general, requires sustained visual attention on a computer screen and, therefore presents a high visual demand, may prove problematic for patients with vision diagnoses following concussion. The possibility of concussion-related vision diagnoses may need to be accounted for when interpreting the ImPACT test results much in the same way that adolescents with attention or other learning disorders may have global difficulty with neurocognitive testing.[40]

In the general population without concussion, there have been randomized clinical trials demonstrating the effectiveness of vergence/accommodative therapy for the treatment of convergence insufficiency and accommodative insufficiency.[41-44] In addition, preliminary studies have shown promise for this type of therapy for the vision deficits following concussion in adults.[45] Our results suggest that office-based vergence/accommodative therapy for vision disorders following concussion in adolescents warrants further study.

Limitations of our study include a potentially more clinically complicated sample than is seen in the general population with concussion. The Minds Matter Concussion Program at The Children's Hospital of Philadelphia is a subspecialty referral program, and as such, our cohort may represent a concussion population with a greater likelihood of prolonged/complicated recovery or vision diagnoses than is seen in the general pediatric concussion population. Although we did not have a control group, published prevalence rates of these vision diagnoses in the general pediatric population are much lower than the high prevalence of vision diagnoses following concussion in our cohort.

In our study, the 29% of patients less than 1 month postinjury were more likely to have vision deficits than the 22% of patients greater than 3 months postinjury, which was statistically significant. This may indicate that vision diagnoses are a significant component of immediate postconcussion symptomatology, and, in some cases, may recover spontaneously on their own. It is possible that vision diagnoses are present in the estimated 80% to 90% of concussion patients who recover spontaneously over the course of a few weeks,[46] and therefore, presumably, their vision problems have also spontaneously recovered. While vision diagnoses are also seen in those with prolonged recoveries in our study, further study is needed to determine if they represent a negative prognostic predictor for complicated concussion recovery. Future study is also needed to determine which symptoms are an accurate predictor of the presence of these vision diagnoses, as the PCSS does not appear to identify a majority of patients with vision diagnoses while the CISS appeared to do better. A prospective longitudinal study will be required to answer these important questions.

Given the high prevalence of vision diagnoses after concussion in the adolescent population, future studies should try to establish efficient clinical screening tools, such as the VOMS or CISS, that could be used by a pediatrician to identify the subset of patients who require further concussion care and comprehensive vision evaluation. In addition, a randomized controlled clinical trial is necessary in order to evaluate the potential benefits of possible interventions, such as vergence/accommodative therapy, for patients with vision diagnoses after concussion.

## Conclusion

Vision diagnoses are prevalent in adolescents with concussion and include convergence insufficiency, accommodative disorders and saccadic dysfunction. Symptoms of these problems may include double vision, blurry vision, headache, difficulty with reading or other visual work, such as the use of a tablet, smartphone, or computer monitor in the school setting. This likely represents a significant morbidity for adolescents whose primary work is school, which is heavily visually oriented. Recognition of these deficits is essential for clinicians who care for patients with concussion and the CISS may prove to be a useful screening tool for use in the future. Identification of these vision diagnoses will help physicians design necessary academic accommodations for patients who have visual deficits and are attempting to reintegrate into school and learning while recovering from concussion.

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### Author Contributions

CLM made a substantial contribution to the concept and design, acquisition of data and analysis and interpretation of data, drafted the article and revised it critically for important intellectual content and approved the version to be published.

MS, MG, AG, RLR and MFG made a substantial contribution to the concept and design, acquisition of data and analysis and interpretation of data, revised the article critically for important intellectual content and approved the version to be published.

SRM made a substantial contribution to the analysis and interpretation of data, revised the article critically for important intellectual content and approved the version to be published.

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