# Vision and Vestibular System Dysfunction Predicts Prolonged Concussion Recovery in Children

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# Abstract

Objective: Up to one-third of children with concussion have prolonged symptoms lasting beyond 4 weeks. Vision and vestibular dysfunction is common after concussion. It is unknown whether such dysfunction predicts prolonged recovery. We sought to determine which vision or vestibular problems predict prolonged recovery in children. Design: A retrospective cohort of pediatric patients with concussion. Setting: A subspecialty pediatric concussion program. Patients (or Participants): Four hundred thirty-two patient records were abstracted. Assessment of Risk Factors: Presence of vision or vestibular dysfunction upon presentation to the subspecialty concussion program. Main Outcome Measures: The main outcome of interest was time to clinical recovery, defined by discharge from clinical follow-up, including resolution of acute symptoms, resumption of normal physical and cognitive activity, and normalization of physical examination findings to functional levels. **Results:** Study subjects were 5 to 18 years (median = 14). A total of 378 of 432 subjects (88%) presented with vision or vestibular problems. A history of motion sickness was associated with vestibular dysfunction. Younger age, public insurance, and presence of headache were associated with later presentation for subspecialty concussion care. Vision and vestibular problems were associated within distinct clusters. Provocable symptoms with vestibulo-ocular reflex (VOR) and smooth pursuits and abnormal balance and accommodative amplitude (AA) predicted prolonged recovery time. Conclusions: Vision and vestibular problems predict prolonged concussion recovery in children. A history of motion sickness may be an important premorbid factor. Public insurance status may represent problems with disparities in access to concussion care. Vision assessments in concussion must include smooth pursuits, saccades, near point of convergence (NPC), and accommodative amplitude (AA). A comprehensive, multidomain assessment is essential to predict prolonged recovery time and enable active intervention with specific school accommodations and targeted rehabilitation. Key Words: concussion, pediatric, vision, accommodative amplitude, near point of convergence, vestibular

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# INTRODUCTION

An estimated 1.1 to 1.9 million children sustain concussions annually in the United States,<sup>1</sup> and this may represent an underestimate,<sup>2</sup> constituting a substantial injury burden in childhood. Although most children with concussion will recover within 2 to 4 weeks of injury,<sup>3,4</sup> anywhere from 10% to 30% of children may experience prolonged symptoms,<sup>5–7</sup> which affects their school attendance and performance, sports and recreation participation, and overall quality of life.<sup>8</sup>

Submitted for publication January 24, 2017; accepted July 22, 2017. From the "Division of Orthopaedics, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania; <sup>†</sup>Department of Pediatrics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania; <sup>‡</sup>Department of Pathology and Laboratory Medicine, Weill Cornell Medicine, New York, New York; and <sup>§</sup>Department of Biostatistics and Epidemiology, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved. http://dx.doi.org/10.1097/JSM.000000000000507 A clinical risk score to predict symptoms lasting longer than 28 days in children presenting to the emergency department primarily incorporates elements obtained in a typical history of a child with concussion, such as age 13 years or older, female sex, history of physician-diagnosed migraine, previous concussion with symptoms longer than 1 week, headache, sensitivity to noise, fatigue, and answering questions slowly. The only physical examination finding included in this clinical risk score is a balance deficit of 4 or more errors on the tandem stance of the Balance Error Scoring System.<sup>9</sup>

Other physical examination findings are noted after concussion and include vision and vestibular dysfunction, such as provocable symptoms with smooth pursuit, saccades, and vestibulo-ocular reflex testing,<sup>10</sup> abnormal binocular near point of convergence (NPC), and monocular accommodative amplitude (AA).<sup>10–13</sup> These vision and vestibular problems may have a significant impact on children and their performance in school, given the high visual workload associated with academics. Persistent symptoms of eyestrain, visual fatigue, headaches, dizziness, and difficulty with near visual work can be debilitating in children, and school accommodations targeting these problems become essential to returning a child to learning.<sup>10–14</sup> Rehabilitation therapies have increasingly been designed to target these systems to ameliorate associated symptoms, including vestibular therapy<sup>15–17</sup> and binocular vision

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rehabilitation.<sup>18</sup> Identifying pediatric patients at risk for prolonged concussion symptoms related to these physical examination deficits and provocable symptoms would help clinicians tailor concussion management plans to individual factors.

As a diffuse type of brain injury, concussion may affect several systems simultaneously and emerging evidence points to vision and vestibular system dysfunction after concussion.<sup>19,20</sup> Vision and vestibular systems are interconnected, with vestibular projections at the brainstem level to the extraocular motor nuclei, controlling eye movements, as well as projections at the cortical level to the vestibular area in the parietal lobe and prefrontal area.<sup>21</sup> The prefrontal cortex is an important locus for eye movement control, as it includes the frontal eye fields (FEFs) and dorsolateral prefrontal cortex. Both areas serve important roles in visual attention and executive function, thereby accounting, in part, for the varied symptomatology often observed after concussion and providing a potential rationale for their co-occurrence. Advanced imaging techniques have identified these as affected areas of interest in concussion,<sup>22</sup> and the targeted physical examination of these systems may provide insight into the underlying injury pathophysiology and potential targets for therapy.

The purpose of this study was to determine which vision and vestibular problems upon presentation for clinical care predicted prolonged symptom recovery in pediatric concussion. We sought to examine any interrelationships between vision and vestibular dysfunction on physical examination, identify any predisposing factors to having such dysfunction, and characterize any differences between those presenting to a concussion program within 14 days after injury versus those presenting later.

# METHODS

# Subjects

We conducted a retrospective cohort study approved by our Institutional Review Board of 432 randomly selected pediatric patients out of a total 3430 patients, representing a 13% sample, aged 5 to 18 years who presented within 1 year of injury with a new diagnosis of concussion using the International Classification of Diseases, Ninth Revision codes 850.0, 850.1, 850.11, 850.12, 850.2, 850.3, 850.4, 850.5, or 850.9 to The Children's Hospital of Philadelphia Minds Matter Concussion Program between July 1, 2014, and June 1, 2016. The diagnosis of concussion was made at the initial clinical visit with a pediatric sports medicine physician using the definition of concussion as an injury caused by direct or indirect forces to the head resulting in temporally related somatic, cognitive, sleep, behavioral, or emotional symptoms of concussion, as described in the Consensus Statement on Concussion in Sport from the fourth International Conference on Concussion in Sport.<sup>23</sup> Patients with intracranial hemorrhage or previous neurologic surgery were excluded. The mechanisms of injury for patients were either sports- or recreation-related or a comparable low-energy mechanism of injury, such as a fall.

## Procedures

Standard demographics, injury details, patient-reported current and past medical history of physician-diagnosed conditions, symptoms on the standardized Post Concussion Symptom Scale (PCSS),<sup>24</sup> and physical examination findings during the initial and final patient visits were all abstracted from the electronic medical record (EMR) into Research Electronic Data Capture (REDCap) tools<sup>25</sup> hosted at The Children's Hospital of Philadelphia for subsequent analysis.

The standardized physical examination was performed by sports medicine-trained pediatricians at The Sports Medicine and Performance Center of The Children's Hospital of Philadelphia. The examination findings were documented in a standardized template in the EMR. The examination included a standardized assessment of tandem gait task performance in which the patient walked in a straight line forward and backward with eyes open and closed. Each condition was documented and the condition noted as abnormal if the patient raised arms from their side for stability, widened their gait, had significant truncal sway, or stepped off the line.<sup>10</sup> A standardized vestibulo-ocular motor screen<sup>10-19</sup> was also performed, including a determination of symptom provocation with smooth pursuits, saccades, and vestibulo-ocular reflex (VOR) testing, as well as objective measurements of NPC and AA. NPC and AA were measured using a standard Astron accommodative rule (Gulden Ophthalmics, Elkins Park, Pennsylvania) with a single column 20/30 card.<sup>26</sup> Abnormal NPC was defined as greater than or equal to 6 cm, and abnormal AA was defined based on the Hofstetter formula, which is age-adjusted.<sup>26</sup>

## **Outcome Measures**

The main outcome measure was time to clinical recovery defined by discharge from clinical follow-up. Clinical recovery was determined by the sports medicine-trained pediatrician, based on a comprehensive clinical functional assessment, including resolution of acute concussion symptoms, resumption of normal physical and cognitive activity, and normalization of physical examination findings to functional levels consistent with the Berlin Consensus Statement on Concussion in Sport.<sup>27</sup>

## Analysis

Descriptive statistics were used to describe means, ranges, medians, and interquartile ranges (IQRs). Statistical analysis was performed using R version 3.2.4 and 3.3.3. To determine whether categorical vision and vestibular physical examination dysfunction co-occurred in reproducible patterns within our cohort, we performed hierarchical cluster analysis using a Manhattan distance metric to determine the pattern of association. Differences between those presenting to the concussion program less than 14 days after injury and those presenting later were investigated. For categorical variables, the Fisher exact test was used. For numeric data, an unpaired t test was used. Kaplan-Meier curves and log-rank tests for significance were performed in R using survival package 2.39-4 on the cohort that presented within 14 days after injury to determine the predictive value of physical examination dysfunction on concussion recovery within this subgroup.

# RESULTS

#### Patient Characteristics

A total of 432 patients were included in the analysis. Patient demographics are presented in Table 1. The cohort is composed of a majority of female adolescents with private

TABLE 1. Patient Characteristics		
Variable	Total Sample ( $n = 432$ )	
Sex, n (%)		
Females	253 (59)	
Males	179 (41)	
Age, y (IQR)	14 (IQR 12-16)	
Insurance, n (%)		
Private	359 (83)	
Public	67 (16)	
Sports-related, n (%)	245 (57)	
Comorbidities, n (%)		
Motion sickness	123 (28)	
Migraine	80 (18)	
Anxiety	69 (16)	
Depression	47 (11)	
Attention-deficit disorder	39 (9)	
Symptoms at presentation, n (%)		
Headache	363 (84)	
Dizziness	214 (50)	
Balance problems	149 (34)	
Visual problems	124 (29)	
Sensitivity to noise	114 (26)	
Feeling "slow"	101 (23)	
Physical examination deficits at presentation, n (%)		
Saccades	355 (82)	
Balance	285 (68)	
Smooth pursuits	285 (66)	
Vestibulo-ocular reflex	275 (66)	
NPC	147 (35)	
Accommodation	93 (22)	
Time to resolution, d (IQR)	86 (IQR 40-146)	

insurance sustaining sports-related concussion presenting with headache, as well as vision and vestibular dysfunction. Presentation to the concussion program occurred a median of 14 days after injury (IQR 7-26). Median time to clinical recovery for the entire cohort was 86 days (IQR 40-146) and is displayed in a survival curve provided in Figure 1.

#### Early Versus Later Presentation to Concussion Program

Two hundred thirty-four (54%) subjects presented to the concussion program within 14 days of injury. A histogram of time to presentation is provided in **Supplemental Digital Content 1** (see **Supplemental Figure 1**, http://links.lww. com/JSM/A155), demonstrating that the majority of patients presented within 1 month of injury. The main differences in those presenting greater than 14 days after injury included lower age (P = 0.02), public insurance (P = 0.03), headache (P = 0.047), and time to recovery (P < 0.001). The remaining demographic, historical, and physical examination findings between the groups did not differ.

#### Time to Recovery, Full Cohort



Figure 1. Median time to clinical recovery, N = 432.

#### Clusters of Physical Examination Signs

Two primary clusters of dysfunction were identified: the vision cluster demonstrated an association between abnormal NPC and AA, and the vestibular cluster showed a separate association between deficits in balance and provocable symptoms with assessment of VOR, smooth pursuits, and saccades. Additionally, we noted that subjects within the vision cluster generally, although not exclusively, also exhibited vestibular cluster signs, which suggests that the vision cluster may define a particular subgroup of the vestibular cluster (Figure 2).

#### Characteristics of Concussion Recovery

Among premorbid characteristics, we found that a history of patient-reported motion sickness was associated with the presence of vestibular dysfunction on examination (balance and VOR) within 14 days after injury (P = 0.01). There was a trend toward an association between history of motion sickness and prolonged concussion recovery, but the level did not reach statistical significance (see Supplemental Figure 2, Supplemental Digital Content 2, http://links.lww.com/JSM/A156).

We next examined whether vision and vestibular system problems were predictive of time to recovery. Because those presenting greater than 14 days after injury were already manifesting as those more likely to have prolonged recovery, we chose to focus on the subgroup presenting more acutely, less than 14 days after injury (N = 234). For this subcohort, Kaplan–Meier analysis showed that in the vestibular cluster, deficits in balance, provocable symptoms with assessment of VOR, or smooth pursuits identified within 14 days after injury predicted longer time to recovery (log-rank *P* values of 0.007, 0.001, and 0.02, respectively) (Figure 3A). To determine whether the presence of abnormal NPC/AA in the vision cluster was similarly predictive of concussion recovery, we again stratified Kaplan–Meier curves of time to recovery



Figure 2. Dendrogram of clusters of vision and vestibular dysfunction in pediatric concussion.

by these 2 physical examination deficits. Our analysis showed that abnormal NPC was not predictive of prolonged recovery (log-rank P = 0.13), whereas abnormal AA was (log-rank P = 0.03) (Figure 3B). Additional analyses addressing crossing survival curves<sup>28</sup> and multiple hypothesis testing did not substantially change the reported results and are provided in the **Supplemental Digital Content 3** (see **Supplemental Digital Content 3** (see **Supplemental Digital Content 3**).

# DISCUSSION

To date, concussion remains a clinical diagnosis based on a history of injury with transmitted forces to the head and the temporally related onset of typical concussion symptoms such as alteration of consciousness, amnesia, headache, or dizziness.<sup>23</sup> Historically, symptom scales, such as those contained within SCAT3,<sup>23</sup> have been commonly used to diagnose concussion. More recently, a directed physical examination including assessments of vision and vestibular function has demonstrated utility in identifying dysfunction in both adult and pediatric populations with concussion.<sup>10,11,19</sup> Our analysis would indicate that these assessments provide prognostic value as well.

## Predicting Prolonged Concussion Recovery

The addition of physical examination findings to a comprehensive history with standardized symptom assessment aids in the diagnosis and management of concussion<sup>10,19</sup> and may also identify factors associated with prolonged recovery from concussion.<sup>10,14</sup> A clinical risk score predicting persistent postconcussion symptoms at 28 days is comprised primarily of demographic, medical history, and symptom factors. The only physical examination factor included in the clinical risk score is balance.9 Our study indicates that the identification of vision and vestibular dysfunction may be helpful in predicting prolonged concussion recovery. Those presenting with balance deficits, abnormal AA, as well as provocable symptoms during smooth pursuits and VOR, had significantly prolonged recovery times compared with those without dysfunction in these domains at presentation for care (Table 2). We had previously described the various recovery trajectories of those with abnormal NPC in a smaller subset of this cohort,<sup>14</sup> but this represents the first description of abnormal AA predicting prolonged concussion recovery. Because convergence is a function that involves the oculomotor, as well as autonomic, system for accommodation, assessment of both NPC and AA may identify multiple systems affected in concussion.4

# Hierarchical Clustering of Physical Examination Dysfunction in Concussion

Balance deficits are observed in concussion<sup>30</sup> and associated with prolonged concussion recovery,<sup>19</sup> and an assessment of balance is the single physical examination component of a proposed clinical risk score predicting persistent postconcussion symptoms beyond 28 days in children.<sup>9</sup> In our analysis, a balance deficit within 14 days after injury is also predictive of prolonged recovery and is associated with other dysfunction of the vision and vestibular systems, namely smooth pursuits, saccades, and VOR. In our cohort, balance deficits and symptom provocation with assessment of VOR



VOR - vestibulo-ocular reflex, NPC - near point of convergence

Figure 3. Kaplan–Meier survival curves for concussion recovery comparing study subjects with and without vision and vestibular dysfunction <14 days after injury, N = 234. A, Vision cluster. B, Vestibular cluster.

and smooth pursuits were significantly associated with prolonged concussion recovery. Our hierarchical cluster analysis also found that, within the related, but distinct vision cluster, which includes abnormal NPC and AA, abnormal AA predicted prolonged concussion recovery.

Our findings indicate that the vision and vestibular systems, although separate, are linked together through higher-level integrative functions critical to our ability to use visual input to manage motion in 3-dimensional space. Vestibular projections have been found to activate several frontal regions including the dorsolateral prefrontal cortex,<sup>31</sup> and the middle and superior frontal gyri within the FEFs, potentially representing vestibular influence on saccadic and smooth pursuit control.<sup>31–35</sup> In addition, cortical areas, such as the FEF, play a role in modulating both convergence and accommodation as part of the near triad of convergence, accommodation, and

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on the Presence or Absence of Vision or Vestibular System Dysfunction in Subjects Presenting for Care <14 Days After Injury (N = 234)			
	Median Time to Recovery		
Variable	+	-	
Vestibulo-ocular reflex	107	53	
Balance	107	47	
Accommodative amplitude	150	81	
Smooth pursuits	95	60	

TABLE 2 Median Time to Recovery Based

miosis.<sup>29,36</sup> It is known that accommodation deficits contribute substantially to convergence insufficiency outside concussion,<sup>26</sup> thus it is not surprising to see abnormal accommodation contributing to convergence insufficiency after concussion. In addition, a notable subset of our cohort with abnormal NPC and AA also had abnormal balance, and provocable symptoms with saccades, smooth pursuits, and VOR testing. These data further reinforce our understanding of the interrelationship between these systems, providing clinical evidence that the vision and vestibular systems, although distinct, are integrally interconnected. In addition, we present preliminary evidence that a history of motion sickness may represent a host factor that may predispose to vestibular system dysfunction after concussion, warranting further research to better understand this relationship.

Of interest, a residual percentage of study subjects in our cohort reported baseline symptoms at a rate of approximately 20%, even when they had no findings on clinical examination and had fully returned to normal levels of physical and cognitive activity. This observation is consistent with recent reports that baseline rates of concussion symptoms, which are not specific to concussion, are prevalent in the uninjured population<sup>37</sup> and, therefore, are likely to be seen in the postinjury recovered population as well. This highlights the need for objective measures of concussion, as well as an assessment of preinjury symptom-burden whenever feasible. Physical examination of the vision and vestibular systems is a means by which provocable symptoms and objective physical examination measures may be obtained. Clinicians should recognize that not all children are symptom-free before injury and having low-grade symptoms should not be the basis for restricting return to normal cognitive and physical daily activities of childhood, especially given emerging evidence that exercise later in the course of concussion recovery may actually be beneficial.38-40

## Factors Associated With Later Presentation for Subspecialty Care for Concussion

Younger age, public insurance, and presence of headache differentiated the subjects that presented to the concussion program greater than 14 days after injury. Difficulty in assessing symptoms in younger children highlights the need for objective measures of concussion. The disparity between those with public versus private insurance may reflect issues of access to care for affected populations. Persistent headache is an understandable factor causing patients to seek care with a subspecialist later in the course of recovery. Because it is unknown whether delayed time to presentation for subspecialty care may represent a risk factor for prolonged recovery, further study is warranted to better understand these characteristics and their impact on clinical outcomes.

#### Limitations

This retrospective cohort may represent a more complicated referral specialty population, with resultant selection bias including those tending toward prolonged recovery. This cohort does not represent an acutely injured population presenting immediately 1 to 2 days after injury. Further study is needed to determine whether vision and vestibular dysfunction are present in the first few days after injury and have the same prognostic value in that context. In addition, although physical examination assessment of balance, NPC, and AA represent objective signs and measures, the assessment of smooth pursuits, saccades, and VOR remain based on subjective patient-reported symptom provocation, highlighting the need to develop objective measures of these domains.

## Importance of Directed Comprehensive Physical Examination in Concussion

Standardized symptom scales have played an important role in the diagnosis and management of concussion.<sup>23,24</sup> Our study supports the addition of directed assessments of the vision and vestibular systems, as they identify dysfunction in systems that might require accommodations in school during recovery such as larger font, preferential seating near the front of the classroom, preprinted notes to minimize provocative saccadic movements while note-taking, and extra time in hallways due to increased vestibular motion sensitivity.

Measurements of NPC/AA and symptom provocation with assessments of smooth pursuits and saccades are not part of standard vision testing, nor is accommodation routinely measured in patients with concussion.<sup>10,11,19,41,42</sup> Our study suggests that an expanded view of the vision system beyond visual acuity is necessary and should include these assessments. This multimodal approach may be warranted specifically in pediatric patients to identify dysfunction that has important implications for management because they impact a child's ability to return to school. Identifying vision and vestibular dysfunction could prompt the specific provision of academic accommodations needed to successfully return a child to the academic setting. In addition to providing prognostic information regarding recovery, vision and vestibular assessments may identify areas that may be targeted for rehabilitation.<sup>15–18,42</sup> This would be consistent with the emerging principle that concussion diagnosis and treatment is increasingly multimodal in nature.<sup>4,15–18,39,40,43</sup>

# CONCLUSIONS

Vision and vestibular dysfunction is prevalent after concussion in children and co-occur in vision and vestibular clusters. A history of patient-reported motion sickness is associated with the acute presentation of balance deficits and provocable symptoms with VOR assessment after concussion. Vision and vestibular dysfunction, including balance and accommodation, as well as symptom provocation with VOR and smooth pursuit testing predicts prolonged concussion recovery. Because these vision and vestibular problems may have a profound impact on a child's ability to return to learn, it is important to consider the use of comprehensive assessments of the vision and vestibular systems in the routine clinical evaluation of concussion in children to develop personalized concussion management plans to optimize individual outcomes.

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