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Vestibular Deficits Following Youth Concussion

Daniel J. Corwin, MDⁱ, Douglas J. Wiebe, PhD^{ii,iii}, Mark R. Zonfrillo, MD, MSCE^{i,iii,iv}, Matthew F. Grady, MD^{iii,v,vi}, Roni L. Robinson, MSN, CRNP^v, Arlene M. Goodman, MD^{vii}, and Christina L. Master, MD^{iii,v,vi}

ⁱDivision of Emergency Medicine, The Children's Hospital of Philadelphia, Philadelphia, PA

ⁱⁱDepartment of Biostatistics and Epidemiology, University of Pennsylvania, Philadelphia, PA

ⁱⁱⁱPerelman School of Medicine, University of Pennsylvania, Philadelphia, PA

^{iv}Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, Philadelphia, PA

^vSports Medicine and Performance Center, The Children's Hospital of Philadelphia, Philadelphia, PA

^{vi}Department of Pediatrics, The Children's Hospital of Philadelphia, Philadelphia, PA

^{vii}Pediatric Sports Medicine, Saint Peter's Sports Medicine Institute, Somerset, NJ

Abstract

Objective—To characterize the prevalence and recovery of pediatric patients with concussion who manifest clinical vestibular deficits, and to describe the correlation of these deficits with neurocognitive function, based on computerized neurocognitive testing, in a sample of pediatric patients with concussion.

Methods—This was a retrospective cohort study of patients age 5–18 years old with concussion referred to a tertiary pediatric hospital-affiliated sports medicine clinic from 7/1/2010–12/31/2011. A random sample of all eligible patient visits was obtained, and all related visits for those patients were reviewed.

Results—247 patients were chosen from 3740 eligible visits for detailed review and abstraction. 81% showed a vestibular abnormality on initial clinical exam. Those patients with vestibular signs on initial exam took a significantly longer time to return to school (median 59 days vs. 6 days, $p=0.001$) or to be fully cleared (median 106 days vs. 29 days, $p=0.001$). They additionally scored more poorly on initial computerized neurocognitive testing, and took longer for neurocognitive

Corresponding Author: Christina L. Master, MD, CAQSM, Pediatric and Adolescent Sports Medicine, Division of Pediatric Orthopedics, The Children's Hospital of Philadelphia, 34th and Civic Center Blvd, Philadelphia, PA 19104, Phone: 215-590-1527, Fax: 215-590-1501, masterc@email.chop.edu.

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deficits to recover. Those patients with three or more prior concussions had a higher prevalence of vestibular deficits and took longer for those deficits to resolve.

Conclusion—Vestibular deficits in children and adolescents with a history of concussion are highly prevalent. These deficits appear to be associated with extended recovery times and poorer performance on neurocognitive testing. Further studies evaluating the effectiveness of vestibular therapy on improving such deficits are warranted.

Keywords

concussion; mild traumatic brain injury; vestibular deficit; balance dysfunction; vestibular rehabilitation therapy

Sports- and recreation-related concussions are common injuries in children and adolescents. Studies have estimated that 144,000 children and adolescents are seen in emergency departments for concussion annually,¹ with the full incidence of concussion in both youth and adult populations estimated to be as high as 3.8 million per year.^{2,3}

Balance and vestibular ocular reflex (VOR) deficits, secondary to dysfunction of the vestibular system, have been recognized as a key component of the morbidity from concussions.^{4,5} The vestibular system is made up of central (including the vestibular nuclei, cerebellum, autonomic nervous system, thalamus, and cerebral cortex) and peripheral (semicircular canals, otoliths, vestibular ganglia, and the vestibular nerve) components,⁶ and given its widely distributed locations, is vulnerable to translated forces occurring during a traumatic brain injury.⁷ Even though prior studies have examined vestibular symptoms of concussion, including dizziness, balance problems, and visual deficits,^{8–10} physical findings indicative of vestibular injury during recovery from youth concussion and their correlation with recovery outcomes have not been described.

By examining a sample of patients referred to a specialty pediatric sports medicine clinic for concussion, this study aimed to (1) describe the prevalence of vestibular deficits in youth concussion; (2) identify any association of vestibular deficits with prolonged recovery from youth concussion; (3) correlate vestibular deficits in youth concussion with results of computerized neurocognitive testing; and (4) determine if prior history of concussion influenced prevalence and severity of vestibular and neurocognitive deficits.

METHODS

We conducted a retrospective cohort study in the subspecialty sports medicine clinics of The Children's Hospital of Philadelphia (CHOP), of a large pediatric tertiary care network, with the goal of identifying risk factors for prolonged recovery from youth concussion. The dataset used in this study was also used in a previous study by Corwin et al describing per-injury characteristics associated with prolonged recovery from concussion.¹¹ The data were collected via an electronic medical record query. A total of 3740 unique visits for patients age 5–18 years with a diagnosis of concussion occurred in the sports medicine clinics between July 1, 2010 and December 31, 2011. A convenience sample of 250 patients was randomly selected via a computerized program based on the estimated workload for data

abstraction. All visits for each patient were identified and charts were abstracted electronically. Eligible patients were those with a diagnosis of concussion (International Classification of Diseases, Ninth Revision; ICD-9 codes 850.0, 850.1, 850.11, 850.12, 850.2, 850.3, 850.4, 850.5, or 850.9) made by the referring provider. This diagnosis was confirmed by the sports medicine physician at the initial visit using the definition of concussion specified in the Consensus Statement on Concussion in Sport 4th International Conference on Concussion in Sport (mechanism of injury that results in direct or indirect forces to head resulting in symptoms including somatic, cognitive, and emotional disturbances).⁵ For the majority of patients seen, the mechanism of injury is sports-related, although some injuries are trauma-related, including motor vehicle crashes, falls, and playground injuries. Those patients seen in the office with non-sports, trauma-related injuries experienced whiplash-type injuries, which were considered to be a low-impact injury mechanism and therefore comparable with sports-related concussion. Patients with high-impact, traumatic injury mechanisms (including motor vehicle crashes with patient ejection, death of another passenger, or rollover; and pedestrian/bicyclist without a helmet struck by a motorized vehicle) are not typically seen in this practice. Patients with intracranial hemorrhage or prior neurological surgery were excluded from the study; however, those with a pre-existing vestibular disorder, substance abuse, or psychiatric disorder were not excluded. Three of the 250 charts were duplicate patients, and thusly excluded. The majority of patients seen in the sports medicine practice are often referred for more severe or prolonged symptoms of concussion from a sports-related injury, but there are also patients who are referred to the clinic immediately after injury regardless of severity or mechanism. Study data were collected and managed using Research Electronic Data Capture (REDCap) tools hosted at The Children's Hospital of Philadelphia.¹²

Demographics, injury details (date, mechanism), physical examination findings during the initial patient visit, and computerized neurocognitive testing scores were all collected from the record. The physical examination, a modified version of the Vestibular/Ocular Motor Screening Assessment validated by the University of Pittsburgh,¹³ is a standardized concussion evaluation performed by physicians at The Sports Medicine and Performance Center at The Children's Hospital of Philadelphia. It includes assessment for dysmetria, nystagmus, smooth pursuits, fast saccades¹⁴ and gaze stability testing (both the horizontal and vertical vestibular ocular reflex), near-point convergence testing,¹⁵ and gait/balance testing. The physical examination, previously published,^{16,17} is conducted in a standardized fashion by three sports-medicine-trained pediatricians. The examination was administered only by these three physicians, and was documented in a standardized template in the electronic health record. Patients were defined as having vestibular deficits if they showed either abnormal vestibular ocular reflex testing, defined as symptom provocation or inability to complete multiple successive repetitions, or abnormal tandem gait, defined as symptom provocation or loss of balance during tandem gait examination.

Outcomes

Patients were classified as suffering from vestibular deficits if they showed abnormalities either on vestibular ocular reflex testing or tandem gait as described above.^{8,9} Recovery outcomes were measured using both clinical and computerized neurocognitive data. Clinical

factors included time until a patient returned to school full-time without academic accommodations (including homebound education, half-days, full days with breaks, elimination of examinations, examinations with extra time and/or note-cards, and elimination of honors classes) and time until a patient was fully cleared to participate in sports by the sports medicine physician. For clearance for sports participation, patients underwent a standard exertional return-to-play protocol, as described in the most recent Zurich guidelines;⁵ and had to be carrying a full cognitive workload at school, be asymptomatic with cognitive and physical exertion and have normal vestibular and oculomotor physical examinations.¹⁷

Neurocognitive testing was performed using Immediate Postconcussion Assessment and Cognitive Testing (ImPACT), a computerized neurocognitive battery that has been designed and validated for evaluating concussion.^{18–20} Four outcome measures are obtained from testing: verbal memory (a composite score for a word recognition paradigm, a symbol number match test, and a letter memory task), visual memory (average percent score for a recognition memory task and an identification memory task), processing speed (the weighted average of three tasks done as interference tasks for the memory paradigms), and reaction time (average response time on three tasks). Both age- and sex-adjusted percentiles from the initial patient visit to the sports medicine clinic, as well as recovery of initial ImPACT score deficits, were used as outcome measures. As the majority of patients seen in the clinic do not have baseline testing scores available, recovery of score deficits was determined to be the date of follow-up visit where a patient's score in each category plateaued, and was therefore considered to have reached their new baseline moving forward. ImPACT testing was performed at the initial patient visit and each subsequent follow-up visit, except in cases where patients were too symptomatic to complete the testing. Finally, data were examined for patients with self-reported history of prior concussion using above outcome measures.

Statistical Analyses

Descriptive statistics included means, ranges, medians, and interquartile ranges (IQR). Statistical comparisons to assess the prevalence or timing of outcomes between subsets of patients were conducted with several methods. Dichotomous outcomes were analyzed using logistic regression. Outcomes classified as times were analyzed using quantile regression given the highly skewed nature of these data and the fact that quantile regression enables valid tests of whether medians are equivalent in this context.²¹ With both regression methods, a test for trend was conducted in instances where the relationship between the exposure and outcome potentially varied in a dose-response fashion. The analysis was conducted using Stata version 12 (College Station, TX).

RESULTS

A total of 247 patients were included in the analysis. Information on patient demographics are presented in Table I. Overall, 81% of patients showed either abnormal gaze stability (vestibular ocular reflex) or abnormal tandem gait on initial physical examination (Table II), with 69% showing abnormal vestibular ocular reflex and 80% showing abnormal tandem

gait. Those patients with either abnormal vestibular ocular reflex or tandem gait took a significantly longer time to return to school (median 59 days vs. 6 days, $p = 0.001$) or to be fully cleared (median 106 days vs. 29 days, $p = 0.001$).

Neurocognitive Outcomes

Those patients with either vestibular sign on initial physical examination showed statistically significant lower ImPACT verbal memory percentile scores (37th percentile vs. 59th percentile, $p = 0.025$), ImPACT processing speed percentile scores (24th percentile vs. 44th percentile, $p = 0.003$), and ImPACT reaction time percentile scores (25th percentile vs. 56th percentile, $p = 0.003$) as compared with those patients without either vestibular sign. Patients with either vestibular examination deficit took nearly three times as long as those patients without either vestibular sign for their verbal memory scores (49 days vs. 16 days, $p = 0.002$), visual memory scores (50 days vs. 14 days, $p = 0.005$), and processing speed scores (43 days vs. 17 days, $p = 0.023$) to resolve or to reach a post-injury baseline.

Prior Concussion History

Overall, 36% of patients had a history of at least one prior concussion (Table III). Although 81% of those patients with two or fewer prior concussions showed either vestibular sign on initial physical examination, 100% of those patients with three or more prior concussions showed vestibular deficits upon initial assessment ($p = 0.004$, test for trend). Those with three or more prior concussions took longer than those with two or fewer prior concussions for abnormal vestibular ocular reflex (median 100 days vs. 33–63 days) and abnormal tandem gait (median 126 days vs. 43–58 days) to resolve, though neither of these values reached statistical significance when testing for trend.

DISCUSSION

This study describes the prevalence and morbidity of vestibular deficits in youth concussion among patients referred to a specialty sports medicine practice, as well as their correlation with neurocognitive data and recovery trajectories. Prior studies have described vestibular deficits, including vertigo, dizziness, and imbalance in concussion,^{8,9} but have neither described the prevalence of such injuries in youth athletes nor their association with recovery outcomes.

We found that 81% of patients seen in our practice showed a sign of vestibular dysfunction, either abnormal vestibular ocular reflex testing or abnormal tandem gait, at initial visit. This is in stark contrast to the general pediatric population, of whom less than 0.5% have been found to exhibit vestibular abnormalities on routine examination.²² Those with either vestibular abnormality took longer to both return to school and to be fully cleared compared with those without such vestibular abnormalities. Even though prior studies have suggested a subset of patients recovering from concussion experience prolonged balance deficits,²³ our study suggests that vestibular abnormalities on initial examination may be indicative of a poorer prognosis. Initial abnormalities in these examination findings may signify more severe neuronal and axonal damage at the time of injury. Recognition and treatment of vestibular injuries, as compared with other physical injuries observed in concussion, may be

delayed, contributing to worse outcomes. Although vestibular therapy has grown significantly over the past decade in adult patients,^{8,10} its use in pediatrics is still limited.²⁴ In terms of prolonged academic recovery, impairment in dynamic gaze stability (vestibular ocular reflex) would seem to affect multiple educational activities, including reading, transcribing, note-taking, and computerized tasks, thus contributing to worse school outcomes for this cohort of patients.

Although neurocognitive testing has been demonstrated in multiple prior studies to have utility in both diagnosis²⁵ and management of concussion,²¹ our study is the first to show a correlation between vestibular deficits and worse performance on neurocognitive testing. Not only was reaction time and processing speed impaired in those patients with vestibular deficits, but there was a significant reduction in visual and verbal memory scores as well, suggesting that the impact on neurocognitive function for those patients with vestibular deficits exist beyond speed tasks. These neurocognitive deficits also took longer to improve following injury in patients with vestibular deficits. Prior studies have shown that patients with vestibular injuries perform worse on cognitive tasks, including short-term memory, concentration, arithmetic, and reading,²⁶ and a “cortico-vestibular” connection has been postulated, possibly secondary to connections between the vestibular system and the frontal cortex.²⁷ Given the prolonged academic recovery of those with vestibular deficits, as described above, recognition of vestibular dysfunction and its associated neurocognitive deficits is imperative. Clinicians should be aware of the cognitive rest protocols that have become standard of care in concussion management (ie initially no school, homework, reading, or electronics to allow symptoms to abate, followed by gradually introducing cognitive activity).⁵

Although not statistically significant, our findings suggest that those patients with three or more concussions take longer to recover from either abnormal vestibular ocular reflex or abnormal tandem gait deficits, and have a higher percentage of vestibular signs on initial presentation than those patients with two or fewer concussion. Previous studies have shown that those patients with three or more concussions are at risk for prolonged recovery,^{28–30} but have not specifically focused on recovery from vestibular deficits. Our findings are consistent with the negative impact a third traumatic brain injury has on patient recovery.

Over the past decade, the field of vestibular rehabilitation therapy has developed significantly. In our cohort, 59% of those patients with vestibular deficits were referred to vestibular therapy, although we estimate that this percentage has increased due to changes in practice since the period of data collection for this study. Vestibular therapy generally consists of exercises that promote habituation (for impaired motion sensitivity), adaptation (for impaired convergence), substitution (for severe impairments), and balance exercises.^{8,9} These therapies have been shown to improve vestibular deficits in adults with mild traumatic brain injury,¹⁰ however studies evaluating pediatric patients suffering from concussion are lacking. Future studies are needed to determine if the vestibular deficiencies and neurocognitive deficits described in this study are improved by vestibular rehabilitation therapy.

Our findings cannot be generalized to concussion in all populations, as our focus was on a subspecialty referral population seen in a sports medicine practice. Presumably, those with less severe injuries would be initially seen, treated, and recover without necessitating referral to a sports medicine specialist. The prevalence of vestibular deficits found in our cohort may be higher than the true prevalence of vestibular deficits in the general population of youth with concussion, most of whom will recover within 2 weeks.³¹ As the time between patient follow-up visits (and subsequent neurocognitive testing) was often several weeks, it is possible that neurocognitive recovery occurred prior to retesting, thereby artificially prolonging our estimated time to neurocognitive recovery in patients both with and without vestibular deficits. As this was a referral population, a gap existed (median 12 days) between the patient's injury and initial specialty visit, which indicates that these patients were already on the path to prolonged recovery. The fact that we only examined data in a single care network also limits the generalizability of our study as other networks may have different patterns of care. Given that the data were collected retrospectively from charts, there were limitations on our ability to standardize outcomes. We did not collect baseline physical examination findings for our patients, and theoretically the vestibular deficits in patients with pre-existing neurologic or psychological disorders may have been a pre-existing finding unrelated to acute injury.

Clinicians caring for youth and adolescents recovering from concussion should be aware of the implications of such physical examination findings on return to learn and return to play. Further studies evaluating the effectiveness of vestibular rehabilitation therapy on improving deficits are warranted.

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Abbreviations

IQR	interquartile range
REDCap	Research Electronic Data Capture
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
VOR	vestibular ocular reflex

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Table 1

Patient demographics

Characteristic	n= 247
All Patients	
Age, years (range)	14 (7–18)
Male, %	58
Days post-injury at first visit, median (range)	12 (1–730)
Sports-related injury, n (%)	190 (77%)
Seen for follow-up visits, n (%)	228 (92%)
Fully cleared at initial visit, n (%)	8 (3%)
Currently following up, n (%)	8 (3%)
Any vestibular deficit, n (%)	200 (81%)
Patients with vestibular deficits referred to vestibular therapy, n (%)	118 (59%)

Table II

Recovery outcomes of clinical and neuropsychological data by vestibular examination findings

Outcome Measure	Any Vestibular Sign	No Vestibular Sign	P-Value	Abnormal Gaze Stability	Normal Gaze Stability	P-Value	Abnormal Tandem Gait	Normal Tandem Gait	P-Value
N (%)	200 (81%)	47 (19%)		115 (69%)	52 (31%)		195 (80%)	50 (20%)	
Median Days Until Fully Cleared (IQR)	106 (36,182)	29 (24,69)*	0.001	106 (34,189)	33 (25,73)*	0.001	108 (38,190)	29 (23,58)*	0.001
Median Days Until Return to School Full Time (IQR) ^a	59 (16,127)	6 (1,20)*	0.001	85 (31,149)	11 (4,22)*	0.001	59 (16,128)	5 (1,19)*	0.001
Median Verbal Memory Percentile (IQR)	37 (13,66)	59 (29,82)*	0.025	35 (10,64)	46 (30,78)*	0.026	37 (13,68)	56 (29,80)*	0.028
Median Visual Memory Percentile (IQR)	29 (6,55)	51 (19,63)	0.227	29 (6,55)	39 (16,63)	0.459	29 (6,55)	51 (16,63)	0.230
Median Visual Motor Speed Percentile (IQR)	24 (1,52)	44 (24,73)*	0.003	24 (1,52)	43 (27,70)*	0.008	23 (1,52)	43 (24,73)*	0.009
Median Impact Reaction Time Percentile (IQR)	25 (6,56)	56 (26,73)*	0.003	22 (5,56)	54 (21,74)*	0.015	25 (6,56)	56 (24,73)*	0.004
Median Days Until Resolution Verbal Memory (IQR)	49 (22,97)	16 (11,29)*	0.002	56 (28,98)	21 (12,78)	0.210	49 (25,97)	18 (13,29)*	0.002
Median Days Until Resolution Visual Memory (IQR)	50 (20,123)	14 (10,23)*	0.005	73 (28,135)	14 (11,27)*	0.001	50 (19,126)	50 (19,126)*	0.002
Median Days Until Resolution Processing Speed (IQR)	43 (16,103)	17 (15,21)*	0.023	47 (21,110)	21 (14,63)	0.258	43 (16,103)	21 (16,28)	0.053
Median Days Until Resolution of Reaction Time (IQR)	45 (14,90)	30 (20,39)	0.100	63 (15,121)	12 (10,57)	0.246	45 (13,85)	33 (16,61)	0.100

* P-value <0.05, regression testing
IQR = interquartile range

Table III

Distribution of outcomes for patients with vestibular deficits by history of prior concussion

Prior Concussion	N (%)	% Vestibular Deficits	Test for Trend, P-Value	Median Days Until Resolution of Abnormal Gaze Stability (IQR)	Test for Trend, P-Value	Median Days Until Resolution of Abnormal Gait (IQR)	Test for Trend, P-Value
None	157 (64%)	75% (118/157) *	0.004	51 (19,77)	0.217	58 (19,127)	0.657
One	54 (22%)	96% (52/54)		33 (17,77)		49 (28,104)	
Two	22 (9%)	77% (17/22)		63 (32,83)		43 (28,79)	
Three or More	13 (5%)	100% (13/13)		100 (54,152)		126 (118,184)	

* P-value <0.05, regression test for trend

IQR = interquartile range