HHS Public Access
Author manuscript
J Sci Med Sport. Author manuscript; available in PMC 2023 September 01.

Published in final edited form as:
J Sci Med Sport. 2022 September ; 25(9): 715–719. doi:10.1016/j.jsams.2022.06.006.

Influence of concussion history and age of first concussion on visio-vestibular function

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Abstract

Objective: To assess if abnormalities on visio-vestibular examination (VVE) are associated with concussion history (first vs. repeat) or age of first concussion in acutely concussed adolescents.

Design: Cross-sectional

Methods: Data were queried from the Children's Hospital of Philadelphia Minds Matter concussion registry. Patients aged 14–18 years old presenting for their initial visit to the specialty care concussion program within 28 days of injury were included. Demographics, including age, sex, concussion history, and age of first concussion, were collected before the exam. The VVE consisted of 9 subtests: smooth pursuit, horizontal/vertical saccades and vestibulo-ocular reflex (VOR), binocular convergence, left/right monocular accommodation, and complex tandem gait. Primary outcomes included VVE subtests (normal/abnormal), and total VVE score (abnormal=2+ abnormal subtests).

Results: Among 1051 patients included (female=604(57.5%); age=15.6±1.2; median lifetime concussions=1 [IQR=1,3]), 518 had repeat concussion. Controlling for age and sex, first vs. repeat concussion was not associated with any VVE subtest or total score (Total VVE Score RR=1.35, 99.5%CI=0.70,2.61). Of those with repeat concussion, 190 had valid age of first concussion data. Controlling for age, sex, and number of lifetime concussions, age of first concussion was not significantly associated with any VVE subtest or total score (Total VVE Score RR=1.11, 99.5%CI=0.78,1.57).

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Declaration of Conflicting Interests: The authors declare that there is no conflict of interest.

Confirmation of Ethical Compliance: The study was approved by the CHOP Institutional Review Board (IRB# 19–016019).

Conclusions: Adolescents with concussion history present with similar visio-vestibular function to those with no concussion history. Additionally, clinical effects of early age of first concussion may not be evident in children. This study provides foundational data regarding potential cumulative effects of concussion in younger athletes.

Keywords

oculomotor; visual; vestibular function tests; mild traumatic brain injury; adolescent

INTRODUCTION

Pediatric concussions continue to be a major public health burden with an estimated 1.1 – 1.9 million sports- and recreation-related concussions occurring in children ≤18 years old in the United States (US) annually.[1] This is particularly concerning as younger athletes may be more vulnerable to the effects of brain injury.[2] This underscores the need for sensitive and clinically meaningful assessment and management of concussive injuries for youth athletes. Additionally, concussion at a young age has been associated with late-life cognitive impairments in former professional football athletes,[3] suggesting the potential for long-term clinical consequences of injury. These studies have primarily focused on outcomes in retired professional athletes, leaving a gap of literature examining the effects of early concussion in youth athletes.

Recent literature has shown that physiological deficits may persist after clinical recovery following concussion suggesting that the injury may influence neurofunction longer than typical recovery times. In youth athletes across a variety of contact and non-contact sports, concussion history has been associated with greater initial symptom endorsement[4] and deficits in dual-task gait[5] following subsequent injury. Further, van Ierssel et al.[6] found that children and adolescents with a previous concussion have four times the risk of sustaining an additional concussion compared to those with no history.[6] Beyond concussion history, the age at which the initial injury or exposure was sustained has additionally become the focus of concussion research. In US collegiate athletes representing various contact, limited-contact, and non-contact sports, a younger age of first concussion has been associated with risk for subsequent concussion[7] and poorer cognitive performance in female athletes.[8] In children, however, studies are limited and findings have been mixed. In a US-based study of adolescent athletes participating in contact, limited-contact, and noncontact sports at the high school and junior high school level, younger age of first concussion was associated with lower global cognition, visual memory, and motor visual scores;[9] however, among children age 9–10 years, younger age of first concussion was not associated with any cognitive outcomes.[10] Rapid neurodevelopment occurring throughout childhood likely affects their response to subsequent injury, thereby warranting further, more comprehensive investigation into any lingering neural response to injury within the pediatric age range. Given the multi-system manifestations of concussion, it is important to examine this question with clinical outcomes beyond cognitive function.

Visual and vestibular function have been established as key components in concussion evaluation and management,[11] and may provide clinical insight into the lasting effects of concussion at a young age. Visio-vestibular dysfunction is evident in the acute and subacute phases following concussion.[12,13] Additionally, Corwin et al.[12] found that impaired vestibular function with concussion was associated with a previous history of 3 or more concussions in children and adolescent patients, though this finding reflected only a small proportion of the total sample (5.3%).[12] Extension of this work is important to understand how any concussion history and age of first concussion may influence visio-vestibular function upon presentation for a subsequent concussion in adolescent athletes. Therefore, the primary purpose of this study was to review data from a large, prospectively collected concussion registry to determine whether history of previous concussion influences performance on the visio-vestibular examination (VVE) upon initial diagnosis of a repeat concussion. Our secondary exploratory aim was to explore how age of first concussion affects VVE performance following a repeat concussion.

METHODS

This study queried prospectively collected data from the Minds Matter Concussion Registry using electronic health records (EHR) for patients seen for concussion within the Children's Hospital of Philadelphia (CHOP) pediatric network. The population for this analysis was limited to patients aged 14–18 years old presenting for their initial visit to the specialty care concussion program as a part of our Sport Medicine and Performance Center within 28 days of injury[14] between January 1, 2018 and August 30, 2020. Patients were diagnosed by a physician trained in concussion using the definition of concussion set forth in the Consensus Statement on Concussion in Sport.[15] The derivation of the study population is described Supplementary Figure 1. The study was approved by the CHOP Institutional Review Board (IRB# 19–016019). The funding sources had no role in the data collection, analysis, or interpretation, or in the right to approve or disapprove publication.

Visio-vestibular function was assessed in patients using a visio-vestibular examination (VVE), a battery of 9 subtests. All six providers contributing to the current study were centrally trained in the administration of the VVE. The VVE assesses smooth pursuit, horizontal/vertical saccades, horizontal/vertical VOR, near point of convergence, left and right monocular accommodation, and complex tandem gait. To determine performance, the VVE considers presence of self-reported symptom provocation (including headache, dizziness, eye fatigue, eye pain, or nausea) (yes/no), physical signs (yes/no), and established repetition-based cut-offs allowing for increased concussion diagnosis sensitivity and a more comprehensive assessment of visio-vestibular function.[16,17] A description of the assessment and definitions of abnormal findings on examination are summarized in Supplementary Table 1. Though similar to the Vestibular/Oculomotor Screening assessment, the VVE was developed to improve the clinical utility of a visio-vestibular exam by expediting the scoring process (binary sign and symptom outcomes (yes/no), use of assessment cut points) and including additional exam elements (monocular accommodation and complex tandem gait).[16,17] The VVE has been feasibly administered across different health care settings,[18,19] and shows fair to moderate agreement between providers and moderate to substantial agreement with the same provider in the emergency department setting.[16] The primary outcomes from the VVE included subtest outcomes (normal vs. abnormal) and total VVE score (abnormal: ≥2 abnormal subtests).[19]

Prior to the start of the exam, patients completed a demographic questionnaire, including age and patient-reported medical history, and physicians used a standardized template within the EHR to document injury, including whether the injury was sports-related, and self-reported concussion history details. Age of first concussion was calculated as the difference in patient date of birth and the self-reported date of first concussion. Patients were excluded if they reported an invalid or missing date of injury or date of first concussion (e.g., clinician or patient failed to document date, missing month, day, or year, documentation error [date of injury or first concussion documented is date of birth or a date in the future]).

Our primary analysis compared VVE abnormalities among patients with their first concussion to those with a repeat concussion (history of ≥1 prior concussion). Descriptive statistics were used to describe patient demographics and characterize concussion history details. Independent samples t-tests were performed to determine group differences in continuous demographic variables (age and days since injury). Chi-square tests were performed for categorical variables (sex and race/ethnicity). Due to non-normal distribution, group differences in the number of lifetime concussions were assessed using Mann-Whitney U tests. Generalized linear models with a log-link function were employed to determine if first vs. repeat concussion was associated with VVE performance, adjusting for age and sex. We conducted a secondary exploratory analysis among patients with a history of prior concussion who reported their age at first concussion to examine the effect of age of first concussion on VVE abnormalities. For our age of first concussion analysis, separate generalized linear models with a log-link function were used to determine if age of first concussion was associated with VVE performance, adjusting for age at current concussion, sex, and number of lifetime concussions. In addition, further exploratory analyses were conducted to assess the influence of concussion mechanism (sport-related versus non-sport related) on the outcomes of interest. From both primary and secondary analytic models, we calculated adjusted risk ratio (RR) and 99.5% confidence interval (CI). To adjust for 10 comparisons per research question, Bonferroni adjusted alpha was set to 0.005 a priori. Based on our sample size, we were 80% powered to find a minimum 8% difference in proportions between groups. Data were analyzed using SAS statistical software, version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

A total of 1051 patients (female=604 (57.5%), mean (SD) age=15.6 (1.2) years) were included in the first concussion vs. repeat concussion analysis (Table 1). Our cohort was similar to the state of Pennsylvania demographics.[20] Five hundred and thirty-three (50.7%) presented with their first concussion and 518 (49.3%) presented with a repeat concussion. Patients with a repeat concussion were slightly older (mean age = 15.8 vs 15.4 years) ($p<0.0001$) and had less time between injury and initial visit (mean days=12.9 vs 14.0 days) ($p=0.02$). Concussion history was significantly associated with race/ethnicity ($p<0.0001$), such that the proportion of Non-Hispanic Black patients in the first concussion cohort was greater than in the repeat concussion cohort (15.8% vs. 4.6%) and the proportion of Non-Hispanic White patients was greater in the repeat concussion cohort than the first concussion cohort (81.2% vs. 70.4%).

Of the full sample, 92.2% of patients had at least two abnormal VVE subtests. When examining patients presenting with their first concussion vs. a repeat concussion, we found no significant associations with any subtest or the total VVE score ($p \geq 0.11$) while adjusting for age and sex (Table 2). There were significant main effects for sex such that females demonstrated greater relative risk for having abnormal testing on smooth pursuit (RR=2.16; 99.5%CI=1.51, 3.09), horizontal saccades (RR=2.30; 99.5%CI=1.54, 3.43), vertical saccades (RR=2.13; 99.5%CI=1.43, 3.17), horizontal VOR (RR=1.94; 99.5%CI=1.20, 3.14), tandem gait (RR=1.66, 99.5%CI=1.10, 2.51), and trended toward abnormal on vertical VOR (RR=1.58; 99.5%CI=0.99, 2.52).

Of the repeat concussion patients, 190 had valid data on the age of their first concussion and were included in the age of first concussion analysis. Relative to the repeat concussion group, the age of first concussion subset was similar in age, race/ethnicity, and days since injury, but included a significantly greater proportion of females (65.3% vs. 57.0%) ($p=0.046$). Additionally, lifetime concussion history distributions differed between groups, though this difference may be driven by a single outlier in the repeat concussion group and was not clinically meaningful ($p<0.0001$). Those included in age of first concussion analysis reported a median age of first concussion of 13 years (IQR=12–15 years) and a median time between first concussion and repeat concussion of 2.0 years (IQR=1.1–3.4 years) (Supplementary Table 2). When examining age of first concussion, we found no significant associations with any subtest or the total VVE score ($p \geq 0.03$) (Table 3).

Nearly two-thirds (62.5%) of the overall sample sustained their injury via sport-related mechanisms. Common non-sport related mechanisms were struck by or against object (14.4%), fall (10.2%) and motor vehicle crash (6.2%). (Table 1) Concussion mechanism (sport-related versus non-sport related) did not influence VVE performance and when the sample was restricted to sport-related concussions only, the effects of concussion history and age of first concussion on VVE performance described above remained consistent.

DISCUSSION

The purpose of this study was to leverage a large clinical concussion registry to primarily examine associations between visio-vestibular function and concussion history (first vs. repeat), and secondarily explore any relationship between visio-vestibular function and age of first concussion in acutely concussed adolescent patients. Our findings indicate that patients presenting with a repeat concussion demonstrate similar visio-vestibular function relative to those presenting with their first concussion. Interestingly, female patients had significantly greater odds than males of testing abnormally on all outcomes. Additionally, among those with a repeat concussion, age of first concussion was not associated with abnormal visio-vestibular function.

Previous studies assessing visual and vestibular impairments separately have found visual deficits in 69% of patients[13] and vestibular deficits in 81% of patients[12] following pediatric concussion. Utilizing an assessment which combines these components, it is unsurprising that our study found a high proportion of at least two abnormal subtests in all of the patients studied, including those with their first concussion (91%) and those with a repeat concussion (93%). We found no associations between concussion history and visio-vestibular function in acutely concussed adolescent patients. While the effects of concussion history on standard clinical assessment are well-studied,[4] these effects in regard to visio-vestibular function are unclear. Similar to the current findings, French et al.[21] found no within-subject differences in Vestibular/Ocular Motor Screening (VOMS) performance in adolescent and young adult patients presenting with their first concussion relative to their second concussion. In contrast, Corwin et al.[12] found that pediatric patients with 3 or more previous concussions presented with worse vestibular function compared to those with 2 or fewer.[12] Our differing results may be due to a more rigorous and standardized method of visio-vestibular assessment, as well as different operational definitions of what constitutes an abnormal test implemented in the current study. Additionally, Corwin et al.[12] likely included more patients in the subacute and chronic phases post-injury (median days post injury=12 days IQR=1,730), whereas the sample in this study had a similar median (13 days) but a much narrower range (IQR=7,19).

The clinical effects of concussion history may also reflect the injury management of previous concussions and/or be influenced by extrinsic, socio-cultural factors. Kroshus et al.[22] found that lower income parents were more likely to view sports as a way to keep children out of trouble and to gain a college scholarship and thus returning to sport may be influenced by this motivation. Additionally, private insurance status has been associated with longer time to return to play in middle, high school, and collegiate student-athletes,[23] suggesting that athletes with private insurance may be treated more conservatively by clinicians. Future research should continue to probe associations between socio-cultural factors and cumulative effects of concussion history on these clinical outcomes.

We also found a main effect for sex such that female athletes had a significantly greater risk of abnormal smooth pursuits, saccadic eye movement, horizontal VOR, and balance relative to males. There were no sex-by-concussion history interaction effects, suggesting sex effects were present regardless of concussion history. Sex differences in clinical outcomes after concussion are well-established. Female athletes present with greater symptom endorsement[24] and longer recovery times post-concussion.[25] Specific to vestibular and oculomotor function, there are mixed results regarding sex differences. Studies assessing near point of convergence[26] and balance testing[27] in adolescent patients have found no sex differences in performance, while studies assessing the Vestibular/Ocular Motor Screening[27] in adolescent patients have demonstrated worse outcomes in females relative to males. Our results add to this growing body of literature and warrant continued study of sex differences in visio-vestibular function.

When examining age of first concussion and the risk of abnormal VVE outcomes, we found no associations between age of first concussion and relative risk of abnormal visio-vestibular function. The study of age of first concussion and exposure to head impacts has grown in the last decade, likely due to the associations between cumulative concussion[28] and head impact exposure[29] with late-life cognitive and psychosocial impairments in former football athletes. There are demonstrated effects of age of first concussion in collegiate athletes, including increased risk for subsequent injury[7] and poorer cognitive function in females.[8] In adolescent athletes, a younger age of first concussion has been associated with increased number of lifetime sport-related concussions,[30] having sustained a concussion in a school sport,[30] and worse cognitive function.[9] In a sample of younger patients (aged 9–10), however, age of first concussion was not associated with any demographic characteristics, sleep disturbance, or cognitive function.[10] Our study is the first to our knowledge to assess associations between age of first concussion and visio-vestibular function. Our results mirror the cognitive results found in the adolescent age group suggesting that clinical effects of early age of first concussion may not be evident in children, but it remains unknown whether they manifest later in adolescence when sustaining a repeat injury.

This study was not without limitations. The patients in our sample were seen within 28 days of injury by physicians in a specialty care concussion program; therefore, our results may not be generalizable to patients presenting to other health care providers (e.g., emergency departments, urgent care) or patients presenting at different time points across the recovery trajectory. We relied on patient self-report for concussion history details including lifetime number and age of first concussion, which is subject to recall bias. We did not collect sport history and therefore are unable to infer the effect of lifetime head impact exposure on visio-vestibular function. We also did not differentiate between sport-related and other mechanisms of injury in our analysis which may be important to consider for future research. For our secondary, exploratory analysis, only 37% of patients with a repeat concussion reported valid date of first concussion data. We recognize that this data is likely not missing at random and may reduce the generalizability of our findings; however, the demographics of the subset with valid data for this exploratory analysis were similar to the overall sample, except for a higher proportion of females. Lastly, our inclusion period extends into the COVID-19 pandemic; 3.6% of our subjects were enrolled from March 2020 through August 2020. We acknowledge that patients reporting to specialty concussion clinics during this time may represent a unique patient population (e.g., more established patients or more severe symptoms).

CONCLUSIONS

In summary, it is critical to examine relationships between concussion history, age of first concussion, and clinical outcomes among adolescent athletes to better inform how concussive injury affects a person across the lifespan, particularly when they sustain a repeat concussion. Visio-vestibular function is a key component in the concussion assessment battery and should continue to be examined as an indicator for brain health. Future work is needed to further assess post-concussion visio-vestibular function and the utility of the VEE as a prognostic tool to better predict concussion recovery in pediatric and adolescent patients. Our study, which leveraged a large clinical EHR concussion registry, suggests that concussion history and age of first concussion do not affect visio-vestibular function following repeat injury. This study provides foundational data regarding the potential cumulative load and lingering neural response to injury on post-concussion visio-vestibular function during adolescence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

Research reported in this publication was supported by National Institute of Neurologic Disorders and Stroke of the National Institutes of Health (grant numbers R01NS097549 and T32NS043126) and the Pennsylvania Department of Health. The funding sources did not have any involvement in study design, collection, analysis, or interpretation of data, writing of the report, or the decision to submit the article for publication. Portions of this data have been presented as a poster at the 2021 American Academy of Neurology virtual conference and as an oral presentation at the 2021 Society for Advancement of Violence and Injury Research virtual conference.

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PRACTICAL IMPLICATIONS

- Neither concussion history nor age of first concussion affect visio-vestibular function following repeat injury.
- Our study further supports known sex differences in clinical outcomes following concussion and warrants continued research of sex differences in visio-vestibular function after concussion.
- The study provides foundational data regarding the potential cumulative load of injury on post-concussion visio-vestibular function in adolescent patients.

Table 1.

Participant demographic and injury history information.

	Total	First Concussion	Repeat Concussion	p-value
Sample, *n(%)*	1051	533 (50.7)	518 (49.3)	
Female, *n(%)*	604 (57.5)	309 (58.0)	295 (57.0)	0.74
Age, years, *mean(SD)*	15.6 (1.2)	15.4 (1.2)	15.8 (1.3)	<0.001
Race/Ethnicity, *n (%)*				<0.001
Non-Hispanic White	795 (75.7)	375 (70.4)	420 (81.2)	
Non-Hispanic Black	108 (10.3)	84 (15.8)	24 (4.6)	
Hispanic	47 (4.5)	23 (4.3)	24 (4.6)	
Non-Hispanic Asian/Asian Pacific Islander/other/multiple race/ unknown	100 (9.5)	51 (9.6)	49 (9.5)	
Lifetime Concussions, *median(IQR)*	1 (1,3)	1 (1,1)	2 (2,3)	<0.001
Days Since Injury, *mean(SD)*	13.5 (7.3)	14.0 (7.4)	12.9 (7.1)	a0.02
Mechanism of Injury, *n(%)*				0.07
Sport-Related	657 (62.5)	328 (61.5)	329 (63.5)	
Non-Sport Related	394 (37.5)	205 (38.5)	189 (36.5)	
Struck by or Against Object	151 (38.5)	76 (37.3)	75 (39.9)	
Struck by Person	54 (13.8)	21 (10.3)	33 (17.6)	
Fall	107 (27.3)	58 (28.4)	49 (26.1)	
Motor Vehicle Crash	65 (16.6)	41 (20.1)	24 (12.8)	
Bicycle-Related	6 (1.5)	3 (1.5)	3 (1.6)	
Pedestrian Struck	3 (0.8)	3 (1.5)	0	
Unknown	1 (0.3)	1 (0.5)	0	
Missing	5 (1.3)	1 (0.5)	4 (2.1)	
Medical History, *n(%)*				
ADHD	156 (14.9)	75 (14.2)	81 (15.7)	0.48
Anxiety	243 (23.3)	114 (21.6)	129 (25.0)	0.19
Bipolar	12 (1.2)	4 (0.8)	8 (1.6)	0.26
Depression	153 (14.6)	69 (13.1)	83 (16.1)	0.17
Learning Disability	110 (10.5)	53 (10.0)	57 (11.1)	0.59
Migraines	157 (15.0)	62 (11.7)	95 (18.4)	0.003
Motion Sickness	104 (10.0)	36 (6.8)	68 (13.2)	0.001

IQR: Interquartile range; ADHD: Attention deficit/hyperactivity disorder

Table 2.

Proportion of participants with abnormal visio-vestibular examination (VVE) outcomes by concussion history, with risk ratio and 99.5% confidence interval adjusting for age and sex.

	First Concussion n=533	Repeat Concussion n=519	Risk Ratio	99.5% Confidence Interval
Pursuits	285 (53.5%)	258 (49.8%)	0.86	(0.60, 1.22)
Saccades				
Horizontal	392 (73.6%)	379 (73.2%)	0.96	(0.64, 1.44)
Vertical	399 (74.9%)	376 (72.6%)	0.87	(0.58, 1.30)
VOR				
Horizontal	448 (84.1%)	438 (84.6%)	1.04	(0.64, 1.69)
Vertical	445 (83.5%)	429 (82.8%)	0.97	(0.60, 1.54)
NPC	108 (20.3%)	88 (17.0%)	0.78	(0.49, 1.22)
Accommodation				
Left Eye	94 (17.6%)	77 (14.8%)	0.85	(0.53, 1.38)
Right Eye	78 (14.6%)	64 (12.3%)	0.87	(0.52, 1.45)
Tandem Gait	145 (27.2%)	129 (24.9%)	0.88	(0.59, 1.32)
Total VVE Score	486 (91.2%)	483 (93.2%)	1.35	(0.70, 2.61)

VOR: Vestibulo-ocular reflex; NPC: Near point of convergence

Table 3.

Proportion of participants with abnormal visio-vestibular examination (VVE) outcomes by age of first concussion, with risk ratio and 99.5% confidence interval adjusting for lifetime concussions, age, and sex.

Dependent Variable	Abnormal n(%)	Risk Ratio	99.5% Confidence Interval
Pursuits	102 (53.7)	0.95	(0.74, 1.20)
Saccades			
Horizontal	88 (46.3)	1.18	(0.92, 1.52)
Vertical	81 (42.6)	1.21	(0.94, 1.56)
VOR			
Horizontal	138 (72.6)	1.02	(0.78, 1.33)
Vertical	136 (71.6)	1.07	(0.82, 1.41)
NPC	33 (17.4)	0.96	(0.69, 1.32)
Accommodation			
Left Eye	32 (16.8)	0.95	(0.68, 1.33)
Right Eye	29 (15.3)	0.97	(0.68, 1.37)
Tandem Gait	35 (18.4)	1.16	(0.88, 1.55)
Total VVE Score	160 (84.2)	1.11	(0.78, 1.57)

VOR: Vestibulo-ocular reflex; NPC: Near point of convergence