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Original Contribution

Use of the vestibular and oculomotor examination for concussion in a pediatric emergency department

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ABSTRACT

Background: Concussion guidelines recommend a vestibular and oculomotor (VOM) examination be performed for all patients with concern for concussion, however the feasibility of performing testing is unknown. We aimed to measure rates of exam performance after implementation of training and support tools in a pediatric emergency department.

Methods: We conducted a retrospective study of patients age 6 to 18 years old presenting over a 12-month period. Charts were obtained via natural language processing, where concussion was suggested as a diagnosis in the electronic health record, and then manually reviewed to record patient and provider factors. A multivariable logistic regression was performed to determine factors associated with exam performance, and a classification and regression tree (CART) analysis was performed to determine if a specific patient type was at risk for not having testing performed.

Results: Four hundred patients were included in the analysis. Sixty-four percent received a VOM examination (including 73% of those diagnosed with concussion). Provider type, concussion history, symptom burden, injury mechanism, and final diagnosis were all significantly associated with exam performance. CART analysis determined patients with a non-concussion diagnosis, a non-sports injury mechanism, no prior history of concussion, and two or fewer symptoms had the lowest likelihood (46%) of receiving the exam.

Conclusion: Performing a VOM examination for concussion is feasible in the acute setting following provider education and using clinical support tools. The exam is more likely to be performed on those children with history or exam findings associated with perceived risk for ongoing symptoms.

1. Introduction

Sports- and recreation-related concussions are common injuries sustained by pediatric and adolescent patients [1]. Balance, vestibular, and oculomotor deficits are a key contributor to morbidity from concussions [2,3]. Prior studies have shown these deficits to be associated with prolonged recovery times [4,5], and, given the eye tracking demands present in the school setting, performing a vestibular and oculomotor (VOM) examination can predict a student's functional deficits following concussion [6]. Recent standardized concussion guidelines recommend a version of the VOM examination be performed for all patients diagnosed with concussion [7,8]. Specifically, the most recent version of the International Consensus Statement on Concussion in Sport, updated in 2017, recommends performing a version of the exam in the acute setting on any patient on whom the diagnosis of concussion is being considered [2]. This testing was developed by sports medicine physicians [9]; however, the majority of concussions are diagnosed by non- sports medicine providers [10]. Therefore, it is important to assess the feasibility of performing the VOM exam in the acute setting, and to determine the subgroup of patients least likely to have this exam completed. The objectives of this study were to [1]: quantify the frequency with which a VOM examination is performed on patients presenting to a pediatric emergency department (ED) in a tertiary care children's hospital following provider training [2], determine factors unique to both the patient and the provider that are associated with the examination not

Abbreviations: CART, classification and regression tree; ED, emergency department; VOM, vestibular and oculomotor.

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being performed, and [3] determine if there is a specific patient type least likely to have a VOM examination performed.

2. Methods

2.1. Study design and patient population

We conducted a retrospective, descriptive study, performed via chart review, of patients age 6–18 years old presenting to a pediatric ED in a tertiary care children's hospital with an acute head injury over a 12-month period (June 1, 2016 to May 31, 2017). Patients were included in the sample if the provider considered concussion as a potential diagnosis. This was defined as when the word "concussion" or synonyms (concussed or concussive syndrome) were listed in the "medical decision making" portion of a patient's electronic medical record, or if the patient was diagnosed with a concussion by International Classification of Diseases-10 code (S06.0X0, S06.0X1, or S06.0X9). Additional inclusion criteria included Glasgow Coma Scale score of 13 to 15 and an Emergency Severity Index of 2, 3, 4, or 5 [11], in order to only include mild traumatic brain injury. Exclusion criteria included patients with underlying neurologic disorders suggesting vestibular or visual dysfunction (including, but not limited to, epilepsy, cerebral palsy, benign paroxysmal positional vertigo, bilateral or unilateral vestibular hypofunction, strabismus, diplopia); subjects who were visibly intoxicated with an illicit substance during the time of presentation who had a positive serum or urine drug toxicology if tested; and subjects with lower extremity trauma preventing them from ambulating to complete gait testing or ocular trauma preventing eye tracking. Following electronic case ascertainment, a manual chart review was performed to confirm inclusion and exclusion criteria and obtain demographic and exposure variables. This study was approved by the Institutional Review Board of The Children's Hospital of Philadelphia.

2.2. Exposure variables

Demographic data obtained included gender, age, race/ethnicity, and type of insurance (private vs. governmental). Additional patient factors abstracted from the patient's chart included the injury mechanism, the number of symptoms at the time of presentation, prior concussion history, and final diagnosis. Visit day of the week and the time of day were collected and converted into a variable quantifying ED patient volume. This was obtained by examining the average patient arrivals per hour in the ED based on the time of day and day of week (168 total hour-long blocks). Any hour-long block whereby the number of patients seen on average per hour was higher than the median number for all hour-long blocks (13 patients/h) was classified as a "busy" hour. Factors abstracted related to the provider included the type of authorizing provider (pediatric emergency medicine physician, pediatrician, or direct-billing nurse practitioner) and number of years the provider had been practicing at our institution (this was chosen to approximate provider experience with the examination, as opposed to the total of number years in practice, given the limited exposure of emergency providers to this examination outside of our institution). If the patient was seen by a trainee, unless otherwise noted, we assumed all documented examinations were performed by the supervising physician. Study data was collected and managed using Research Electronic Data Capture (REDCap) tools hosted at The Children's Hospital of Philadelphia [12].

2.3. Outcome

The outcome variable was the performance and documentation of the vestibular and oculomotor examination. The examination performed at our institution is a modified version of the brief Vestibular/Ocular Motor Screening Assessment (VOMS) validated by the University of Pittsburgh [9], and consists of nine measures. It is standardized across providers in sports medicine, primary care, and emergency medicine at our institution [13]. It includes assessment for nystagmus, smooth pursuits, fast saccades (both horizontal and vertical), gaze stability testing (both the horizontal and vertical vestibular ocular reflex), near-point of convergence testing, monocular accommodation testing, and gait/balance testing (as compared to the VOMS, which includes testing for visual-motion sensitivity but not for dysmetria or gait/balance testing). Our version of the examination taxes approximately 3–5 min to complete. We initially introduced this examination into our ED in 2014. This included provider training, (several tabletop exercises and demonstrations), updating our head injury clinical pathway to include both a description and video demonstration of the examination [14], and by altering our electronic documentation template for "head trauma" to include an optional selection of each exam element. All of these changes were completed at least 12 months prior to the time period in which our data were abstracted. Whether or not any abnormalities were present on the examination was also abstracted. If an examination was partially completed, it was considered in our analysis as "completed."

2.4. Power calculation and statistical analysis

Prior to study initiation, it was determined a sample size of 400 patients would allow an 80% power to detect a 15% difference in the proportion of patients with sports-related injury mechanisms on whom the examination is performed (thought a priori to be the strongest predictor). This calculation was performed using a significance level of 0.05 and assuming an underlying prevalence of examination performance of 0.67 (from unpublished, internal data). The 400 eligible charts were selected randomly.

Demographic and baseline statistics were summarized using standard descriptive statistics. Point estimates and 95% confidence intervals were calculated using the Exact (Clopper-Pearson) method. To determine patient and provider characteristics most strongly associated with the vestibular and oculomotor examination for concussion not being performed, a univariable analysis of all factors was initially performed. Any factor with $p < 0.20$ associated with not having the exam performed was included in the logistic model. A multivariable logistic regression model was then performed. The model developed was then tested using the Hosmer-Lemeshow goodness of fit test and for colinearity using variance inflation factor testing. To test if a specific patient "type" exists most at risk for not having VOM testing performed, a classification and regression tree (CART) analysis of all factors was be performed to determine clusters of patients at highest risk. The classification tree was pruned to 5 branches. The analysis was conducted using Stata version 14.2 (StataCorp, College Station, TX) and XLStat (Addinsoft).

3. Results

A total of 400 patient charts were reviewed for data abstraction. Information on patient demographics is presented in Table 1. Overall, 64% of the patients (95% confidence interval [CI] 59%–68%) received a vestibular and oculomotor examination for concussion. Of those who were ultimately diagnosed with concussion, 73% (95% CI 66%–79%) had a VOM examination performed, while 52% (95% CI 45%–60%) of those who were not diagnosed with a concussion (but were thought to potentially have a concussion based on the provider's documentation) had a VOM examination performed. In the group of patients diagnosed with concussion, 69% (95% CI 62%–76%) of those seen by a pediatric emergency medicine physician, 88% (95% CI 70%–98%) of those seen by a pediatrician, and 92% (95% CI 62%–100%) of those seen primarily by a nurse practitioner received a VOM examination.

Unadjusted and adjusted odds ratios for each variable are provided in Table 2. Following our multivariable analysis, we found a sports injury mechanism (odds ratio [OR] 2.1, 95% CI 1.3 to 3.6), a history of prior

Table 1
Patient demographics.

Characteristic	N (%)
All Patients	400
Mean age in years (range)	11.9 (6–18 years)
Male	241 (60%)
Race/ethnicity	
Non-Hispanic white	117 (29%)
Hispanic white	23 (6%)
Black	241 (60%)
Other	19 (5%)
Insurance	
Private/self-pay	193 (48%)
Medicaid	207 (52%)
Mechanism of injury	
Sports	134 (33%)
Non-sports	266 (67%)
Number of prior concussion	
0	359 (90%)
1 or greater	41 (10%)
Number of symptoms	
0–2	234 (59%)
3 or greater	166 (41%)
Provider type	
Pediatric emergency medicine	301 (75%)
Pediatrician	54 (14%)
Nurse practitioner	45 (11%)
Years of provider at CHOP	
0–5 years	181 (45%)
>5–10 years	101 (25%)
10 or greater years	118 (30%)
Visit during ED busy hours	289 (72%)
Exam completed	254 (64%)
Final diagnosis of concussion	217 (54%)

concussion (OR 2.7, 95% CI 1.1 to 6.8), greater than two symptoms at presentation (OR 1.7, 95% CI 1.0 to 3.0), being seen by a pediatrician as compared to a pediatric emergency medicine provider (OR 5.5, 95% CI 2.3 to 13.1), and a final diagnosis of concussion (OR 1.7, 95% CI 1.0 to 2.9) were all significantly associated with having a VOM examination performed.

The classification and regression tree is showing in Fig. 1. After pruning to 5 branches, we found the cohort least likely to have the exam performed were patients who were ultimately not diagnosed with a concussion, who had no history of prior concussion, who had two or fewer symptoms at presentation, and who had a non-sports mechanism of injury. This group only received a VOM examination 46% of the time.

Table 2
Unadjusted and adjusted odds ratios for predictor variables.

Variable	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Age (Ref: 6–9 years-old)		
10–13 years-old	1.4 (0.8, 2.3)	1.2 (0.7, 2.1)
14–18 years-old	1.1 (0.7, 1.8)	0.8 (0.5, 1.4)
Sex: female (vs. male)	1.1 (0.7, 1.6)	1.1 (0.7, 1.7)
Race (Ref: Non-Hispanic White)		
Black	0.6 (0.4, 1.0)[a]	1.1 (0.6, 1.9)
Other	1.0 (0.4, 2.1)	1.5 (0.6, 3.4)
Insurance: Medicaid (vs. private)	1.6 (1.0, 2.4)[a]	0.7 (0.4, 1.1)
Mechanism: sports (vs. non-sports)	2.4 (1.5, 3.8)[a]	2.1 (1.3, 3.6)[a]
Prior concussion: 1 or more (vs. 0)	3.1 (1.3, 7.1)[a]	2.7 (1.1, 6.8)[a]
Symptoms at presentation: >2 (vs. ≤2)	2.5 (1.6, 3.8)[a]	1.7 (1.0, 3.0)[a]
Provider type (Ref: pediatric EM)		
Pediatrician	4.3 (1.9, 9.9)[a]	5.5 (2.3, 13.1)[a]
Nurse practitioner	0.7 (0.3, 1.4)	1.0 (0.5, 1.9)
Provider years @ CHOP (Ref: 0–5 years)		
>5–10 years	0.8 (0.5, 1.3)	0.9 (0.5, 1.6)
>10 years	0.6 (0.4, 1.0)[a]	0.8 (0.4, 1.3)
ED volume: busy (vs. not busy)	1.0 (0.7, 1.6)	1.2 (0.7, 2.0)
Final diagnosis: concussion (vs. no concussion)	2.4 (1.6, 3.7)[a]	1.7 (1.0, 2.9)[a]

[a] Statistically significant.

Finally, of the 158 children with a concussion who had a completed examination, 9% (95% CI 5% to 14%) had 1 or fewer symptoms but an abnormal examination.

4. Discussion

This study evaluated the use of a vestibular and oculomotor (VOM) examination for concussion in a pediatric ED in a tertiary care children's hospital following provider education and training. Overall, we found that performing a VOM examination in the acute setting is feasible, as 64% of all patients considered to potentially have a concussion had an examination performed. We found that the utilization of the exam was not specific to pediatric emergency medicine providers; in fact, our general pediatricians performed the examination more frequently overall, and our nurse practitioners performed the examination more frequently in patients diagnosed with a concussion. Additionally, providers new to our ED performed the examination as frequently as those long-standing providers. Finally, we found that ED volume, determined by the time of day and the day of week the patient was seen, did not affect the likelihood of receiving the examination.

We found the exam to be performed less often when patients presented with fewer common features of concussion. Specifically, our classification and regression tree analysis demonstrated that those patients with minimal concussive symptoms, no prior history of concussion, and a non-sports injury mechanism were least likely have testing performed. While many children present with both reported symptoms and vestibular and oculomotor abnormalities, we have found that there are a group of children with minimal reported symptoms but an abnormal examination (specifically 9% of the overall number of concussed patients in this study). This likely represents a group of children who would experience symptoms with cognitive and/or oculomotor exertion the following day, a potentially preventable exacerbation with appropriate diagnosis.

There are several benefits to the performance of VOM testing in the acute setting. The most recent Consensus Statement on Concussion, published in 2017, includes vestibular and oculomotor abnormalities as part of the diagnostic criteria for concussion. Additionally, the statement recommends that the acute evaluation of concussion include "a medical assessment including …ocular function, vestibular function, gait and balance." [2] Prior studies have shown that pediatric emergency medicine physicians often misdiagnose or inaccurately diagnose concussion. For example, Boutis and colleagues found that emergency physicians diagnosed only 200 of 443 concussed patients who met diagnostic criteria by Consensus Statement guidelines [15]; Bazarian and colleagues, on other hand, found that of 1000 patients with International Classification of Diseases, 9th Edition codes of concussion, only 516 met clinical criteria [16]. Use of the exam may allow for improved diagnostic accuracy in the ED. Patients with missed diagnoses are at risk for secondary injuries, and prior studies have shown that a second concussion during the recovery phase can lead to extended recovery times [17]. Secondly, as many acute care clinicians struggle to risk stratify concussed patients, the examination may provide information on those at risk for a more severe injury; multiple studies have shown an association with vestibular and oculomotor deficits and a lengthened recovery time [4,5,18]. Finally, as the oculomotor testing portion of the examination mimics the eye tracking demands present in the school setting, the examination can help providers identify tasks with which student may struggle upon return to school [6].

There are several limitations to this study. As this study was conducted via a chart review, we relied on documentation of the provider's medical decision-making to determine cases, and it is possible there were cases where the provider considered concussion but did not document accordingly in the provider note. We tried to correct for this possibility by including discharge diagnosis in addition to natural language processing in our inclusion criteria. Our study was also at risk for

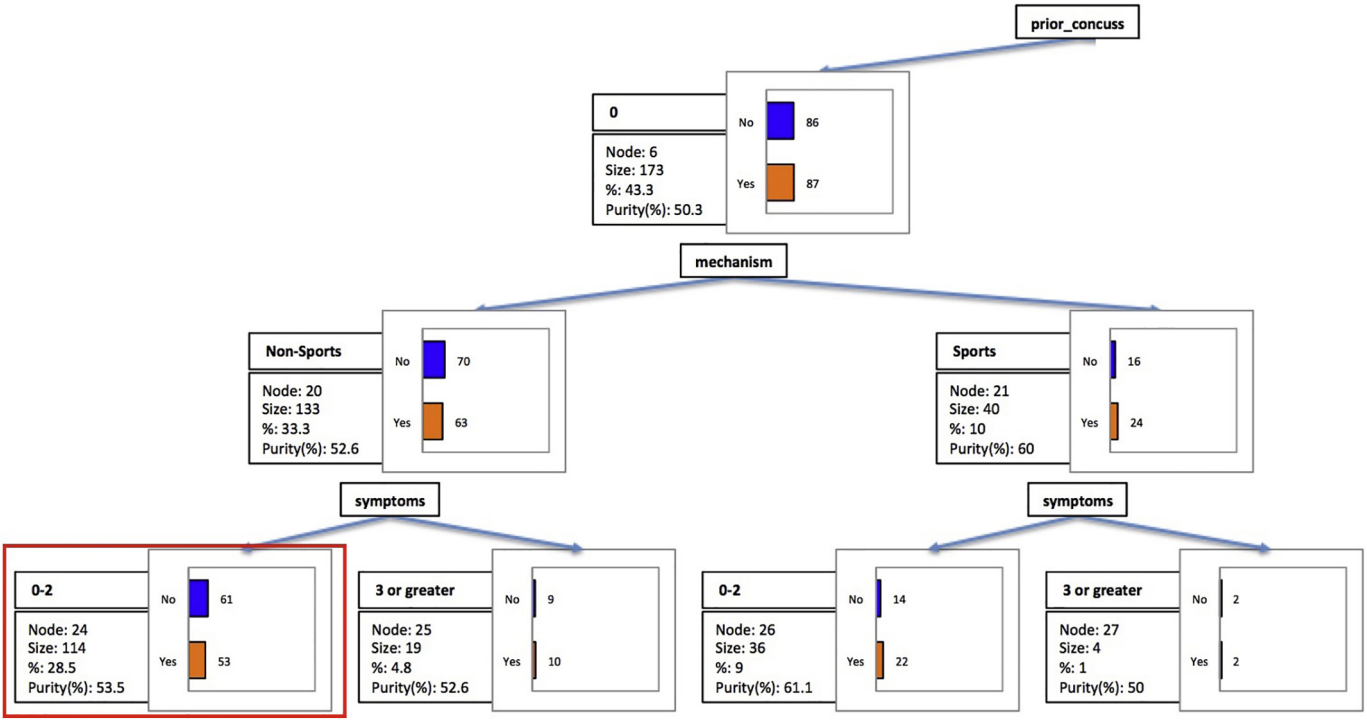

Fig. 1. Selection of classification and regression tree analysis highlighting those patients with no concussion diagnosis, no prior history of concussion, a non-sports mechanism of injury, and 2 or fewer symptoms at presentation (red box).

misclassification bias, whereby the examination was performed but not documented. This would have led us, however, to underestimate the overall percentage of patients who received a VOM examination. Our assessment of provider experience with the examination (measured in this study by evaluating number of years at our institution) by may have been confounded by unmeasured prior personal or professional experiences. Finally, while we evaluated the performance of multiple provider types on performing the VOM examination, our study was limited to one academic, free-standing children's hospital, staffed by pediatric-trained providers. In this setting, there likely is a greater receptiveness to incorporating new examination maneuvers and diagnostic methods into daily practice. However, we feel our methodology in training providers using tabletop sessions, an electronic clinical pathway (available on the internet), and electronic documentation templates is generalizable to other institutions as well as adult emergency medicine providers. Future studies include investigating the use of the examination outside of our medical center, specifically involving adult emergency medicine providers.

5. Conclusions

Performing a VOM exam for concussion is feasible in the ED setting following provider education and using clinical support tools. The exam is more likely to be performed on those children whom the provider feels a concussion may be more likely based on historical elements. More education surrounding exam usage on all patients following head injury with a potential concussion is required to maximize its diagnostic value.

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Conflicts of interest

We declare that we have no conflicts of interest in the authorship or publication of this contribution.

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