Discriminative Validity of Vestibular Ocular Motor Screening in Identifying Concussion Among Collegiate Athletes

A National Collegiate Athletic Association–Department of Defense Concussion Assessment, Research, and Education Consortium Study

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Background: Vestibular and ocular motor screening tools, such as the Vestibular/Ocular Motor Screening (VOMS), are recognized as important components of a multifaceted evaluation of sport-related concussion. Previous research has supported the predictive utility of the VOMS in identifying concussion, but researchers have yet to examine the predictive utility of the VOMS among collegiate athletes in the first few days after injury.

Purpose: To determine the discriminative validity of individual VOMS item scores and an overall VOMS score for identifying collegiate athletes with an acute sport-related concussion (≤72 hours) from healthy controls matched by age, sex, and concussion history.

Study Design: Case-control study; Level of evidence, 3.

Methods: Participants (N = 570) aged 17 to 25 years were included from 8 institutions of the National Collegiate Athletic Association–Department of Defense CARE Consortium (Concussion Assessment, Research, and Education): 285 athletes who were concussed (per current consensus guidelines) and 285 healthy controls matched by age, sex, and concussion history. Participants completed the VOMS within 3 days of injury (concussion) or during preseason (ie, baseline; control). Symptoms are totaled for each VOMS item for an item score (maximum, 40) and totaled across items for an overall score (maximum, 280), and distance (centimeters) for near point of convergence (NPC) is averaged across 3 trials. Receiver operating characteristic analysis of the area under the curve (AUC) was performed on cutoff scores using Youden index (J) for each VOMS item, overall VOMS score, and NPC distance average. A logistic regression was conducted to identify which VOMS scores identified concussed status.

Results: A symptom score ≥1 on each VOMS item and horizontal vestibular/ocular reflex ≥2 significantly discriminated concussion from control (AUC, 0.89-0.90). NPC distance did not significantly identify concussion from control (AUC, 0.51). The VOMS overall score had the highest accuracy (AUC, 0.91) for identifying sport-related concussion from control. Among the individual items, vertical saccades ≥1 and horizontal vestibular/ocular reflex ≥2 best discriminated concussion from control.

Conclusion: The findings indicate that individual VOMS items and overall VOMS scores are useful in identifying concussion in collegiate athletes within 3 days of injury. Clinicians can use the cutoffs from this study to help identify concussion in collegiate athletes.

Keywords: concussion; athlete; vestibular; oculomotor; clinical cutoffs; VOMS; Vestibular/Ocular Motor Screening

Sport-related concussions (SRCs) are heterogeneous injuries that cause temporary neurological dysfunction and generally resolve in the first 2 to 4 weeks after injury.[14,21] While the response to SRC is highly individualized, subjective symptoms and deficits on objective measures can aggregate into clinical profiles or trajectories.[6] For example, 2 common clinical profiles are (1) vestibular, with dizziness, nausea, and vertigo as common symptoms,[2,18,23] and (2) ocular, with convergence insufficiency, blur, diplopia, eye strain, dizziness, and/or headaches as common symptoms/impairments. Both of these profiles are commonly reported after SRC.[11,23] Furthermore, vestibular/oculomotor impairments

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are associated with worse symptom burden, neurocognitive performance, and clinical recovery than in individuals without vestibular impairment.[7,28] Given the prevalence and additional burden of vestibular/oculomotor impairment after SRC, recent clinical research has placed an emphasis on identification and treatment of these impairments through targeted interventions.[1,5,15]

Vestibular screening is a necessary component of the multifaceted evaluation for SRC.[14,21] Traditional measures of the vestibulospinal system have included clinic-friendly balance assessments (eg, Balance Error Scoring System), but deficits in this system typically resolve within 3 to 5 days after concussion.[21] Conversely, an evaluation of the vestibulo-ocular system has historically required costly, sophisticated equipment and extensive time and resources to administer (eg, video-oculography goggles).[12,29] The Vestibular/Ocular Motor Screening (VOMS) is a brief screening assessment of vestibular function and oculomotor integrity after SRC.[23] The VOMS assesses symptom severity on a scale of 0 to 10 for headache, dizziness, nausea, and fogginess, before any testing and immediately after each of 7 component items. Symptoms are noted after each of the 7 items: smooth pursuits, saccades in the horizontal and vertical directions, near point of convergence (NPC), vestibular/ocular reflex (VOR) in the horizontal and vertical directions (H-VOR and V-VOR), and visual motion sensitivity, as well as NPC distance (centimeters). Mucha et al[23] reported that VOMS components had high internal consistency (Cronbach $\alpha = .92$) and that the visual motion sensitivity, VOR, and convergence domains accounted for 61% of the variance for likelihood of concussion. Moreover, a receiver operating curve (ROC) analysis demonstrated an area under the curve (AUC) of 0.89, using visual motion sensitivity, H-VOR, and NPC over clinical cutoffs while controlling for age.[23] While an important contribution to the field, that study was limited by including only adolescents and a broad time since injury (1-21 days) and not a cutoff for the overall VOMS score (ie, the sum of all symptom scores for each VOMS item), which may be clinically useful.

Despite an increased number of reports that support VOMS as a clinical measure after SRC,[10,17,22] further validation work is necessary for VOMS to be widely accepted across diverse age ranges. This is important, as symptom-reporting behaviors have been noted to differ between high school and college-age athletes on similar subjective symptom scales.[8,16] Clinical cutoffs and likelihood ratios for VOMS were established with an adolescent age group ranging from 14 to 18 years at preseason (baseline) and during the postacute injury phase of SRC. Furthermore, the total VOMS score has not been included in previous studies and may have clinical value. The purpose of the current investigation is to determine the discriminative utility of VOMS items (eg, symptoms and item scores) and total VOMS score for identifying collegiate athletes with recent SRC ($\leq$3 days) from healthy controls matched by age, sex, and concussion history. A secondary purpose is to develop VOMS item and total VOMS clinical cutoff scores to identify concussion from healthy control in the current collegiate sample, similar to Mucha et al[23] for adolescent athletes.

METHODS

Design and Participants

The present study was a subanalysis of a data set from the National Collegiate Athletic Association–Department of Defense (NCAA-DoD) CARE Consortium (Concussion Assessment, Research, and Education), comprising collegiate student-athletes and military cadets from 8 institutions. Participants were included in the concussion group if they were a collegiate-level athlete between 17 and 25 years old with a diagnosed symptomatic concussion per current consensus guidelines and had completed VOMS data (n = 570) (Figure 1).[4] Concussion was defined as a blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head that typically results in transient neurological signs and symptoms, which may or may not involve loss of consciousness.[21] The symptoms associated with concussion also cannot be explained by drug, alcohol, or medication use or by other injuries or preexisting comorbidities.[21] Participants were included in the control group from baseline measurement data (ie, preseason) and met the same criteria but with no current concussion. Patients self-reporting previous moderate to severe traumatic brain injury (n = 4), neurological disorder (n = 11), or preexisting vestibular disorder (n = 3) were excluded from analysis.

Procedures

This study was reviewed and approved by each university's institutional review board and the US Army Human Research Protection Office. Eligible participants provided informed consent before study participation. All participants

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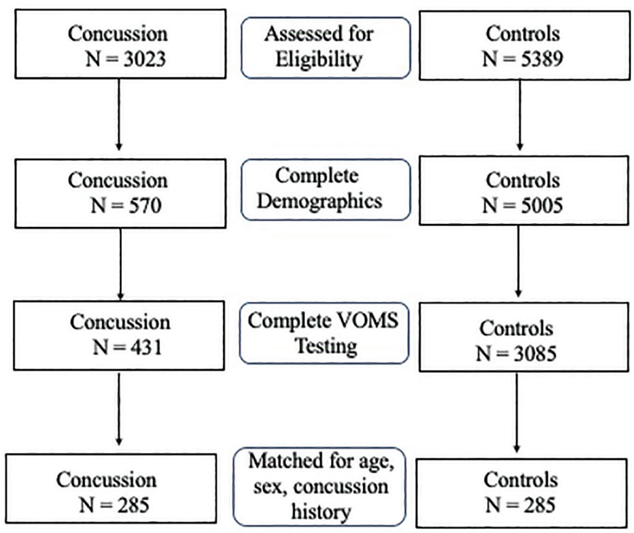

Figure 1. Sampling CONSORT (Consolidated Standards of Reporting Trials) diagram for the current analysis. VOMS, Vestibular/Ocular Motor Screening.

completed a baseline evaluation, which included the VOMS and medical history. The VOMS component of the evaluation required approximately 5 to 7 minutes to complete. All measures were completed per a protocol described elsewhere.[3] Before VOMS data collection, researchers were trained on proper data collection processes per Mucha et al.[23] Data were collected by the same trained individual or the same trained set of individuals, depending on the data collection site.

Measures: Vestibular and Ocular Function

VOMS was conducted in accordance with the initial presentation of the measure, from Mucha et al,[23] where detailed instructions of the test can be located. Before the initiation of testing, participants were asked to rate their current levels of headache, dizziness, nausea, and fogginess on a scale of 0 to 10, where 10 indicates maximum severity. Following each of the 7 VOMS items, symptoms were reassessed to determine the degree of symptoms and impairments. The items include smooth pursuits, horizontal and vertical saccades, NPC, H-VOR and V-VOR, and visual motion sensitivity. VOMS outcomes for the present study were symptom scores for each item (ie, the sum of headache, dizziness, nausea, and fogginess for each item; maximum, 40) and the overall VOMS score (ie, the sum of all symptoms reported for all VOMS items; maximum, 280). The distance for each of 3 NPC trials in centimeters was averaged for a separate outcome not included in the overall score.

Data Analysis

Participant demographic and postinjury VOMS item and overall scores were described as means and standard deviations or frequencies and percentages. Athletes with a concussion and healthy controls were matched for age (within 2 years), sex, and previous concussion (yes/no). Demographic between-group differences were evaluated using independent-samples means test (or nonparametric analog) for continuous variables and contingency table analyses for categorical variables. Mean VOMS overall, symptom, and individual item scores were compared between concussion and control using a nonparametric Mann-Whitney U test, owing to the ordinal scoring and skewed distribution of the VOMS scores.

The optimal cutoff scores for each VOMS symptom score, NPC distance, and overall VOMS score to identify participants with a concussion were determined using ROC analysis of the AUC. The cutoff score and sensitivity/specificity to identify concussion for the scores with the highest AUC were determined with the Youden index (J), which is the maximum of sensitivity + specificity − 1. Specifically, each coordinate point of the ROC curve was plotted (VOMS score of 1, 2, 3, etc) with corresponding sensitivity and specificity values for each point. The value with the highest Youden index was visually selected as the optimal cutoff point. A multivariate forward stepwise logistic regression was conducted to reveal which VOMS item scores were the most robust discriminators of concussed status. Variables were entered in the order that they appeared during VOMS testing, with the criteria for inclusion being optimization of the likelihood ratio for the final model. If multiple VOMS item scores were retained in the model, ROC curves with AUC analyses were conducted again. A type I error rate of $P < .05$ was used for all analyses.

RESULTS

Descriptive Analyses

A summary of participant characteristics is provided in Table 1. There were no differences between groups in sex, concussion history, and attention-deficit/hyperactivity disorder history. Control participants were athletes in 15 sports, with the most common being football (34.7%), cross country/track (15.3%), soccer (10.2%), swimming/diving (9.0%), and softball (6.8%), with all other sports $\leq$2.8%. Participants with a concussion were athletes in 20 sports, with the most common being football (35.1%), soccer (13.0%), basketball (7.0%), volleyball (6.7%), and softball (4.9%), with all other sports $\leq$4.2%. The concussion group was younger and had significantly more participants with migraine history (8.4%) than the matched controls (<1%). Table 2 presents a summary of VOMS item and overall score data. The concussion group reported significantly higher VOMS scores for each item and total VOMS score. Descriptive statistics of headache, dizziness, nausea, and fogginess symptoms for each VOMS item between the concussion and control groups are displayed in Appendix Table A1 (available in the online version of this article).

AUC Analyses and Clinical Cutoffs

AUC analyses for discrimination of concussion versus control are displayed in Table 3. Each item significantly

TABLE 1
Participant Characteristics
With Group Difference Comparisons[a]

	Concussed (n = 285)	Control (n = 285)	*P* Value
Age, y	19.2 ± 1.4	19.8 ± 1.2	<.001[b]
Male	220 (77.2)	218 (76.5)	.94
Concussion history	128 (44.9)	128 (44.9)	>.99
Migraine history	24 (8.4)	1 (0.4)	<.001[b]
ADHD	17 (6.0)	9 (3.2)	.12

[a]Values are presented as mean ± SD or No. (%). ADHD, attention-deficit/hyperactivity disorder.
[b]Significant at $P < .05$.

TABLE 2
Mann-Whitney *U* Analyses of VOMS Symptom
Scores for Concussed Group Versus Matched Control[a]

	Concussed	Control	*P* Value[b]
Smooth pursuit	7.2 ± 6.3	0.4 ± 1.6	<.001
Horizontal saccade	7.5 ± 6.5	0.5 ± 1.6	<.001
Vertical saccade	7.6 ± 6.6	0.5 ± 1.6	<.001
Near point of convergence	7.6 ± 6.7	0.5 ± 1.5	<.001
Near point of convergence, cm	4.3 ± 5.0	3.4 ± 2.6	.014
VOR: horizontal	8.1 ± 6.9	0.6 ± 1.8	<.001
VOR: vertical	8.2 ± 7.1	0.5 ± 1.8	<.001
Visual-motion sensitivity	8.4 ± 7.4	0.6 ± 2.0	<.001
VOMS overall	54.6 ± 47.0	3.5 ± 11.7	<.001

[a]Values are presented as mean ± SD. VOMS, Vestibular/Ocular Motor Screening; VOR, vestibular/ocular reflex.
[b]Each value is significant at $P < .05$.

identified concussion over control with an AUC of 0.90, with the exception of visual motion sensitivity (AUC, 0.89) and convergence distance (AUC, 0.51). VOMS overall score had the highest accuracy (AUC, 0.91) for determining concussion over control.

Multivariate Logistic Regression and ROC Analysis

The final model significantly identified concussion from control (Nagelkerke R^2 = 0.48, $P < .001$). Vertical saccades ≥1 (P = .01) and H-VOR ≥2 (P = .01) were the only included discriminators of concussion. When this 2-factor model was combined and ROC with AUC was assessed, the 2-factor model significantly discriminated concussion from control (AUC, 0.83; $P < .001$) (Figure 2).

DISCUSSION

The current study is the first to establish clinical cutoffs for individual VOMS items and overall scores to assist in identifying concussion in collegiate athletes. The results of this study indicated that individual VOMS items, with the exception of NPC distance, had significant utility in identifying concussion in collegiate athletes (AUC, 0.89-0.90) (Table 3). Each VOMS item had a clinical cutoff score ≥1 to optimize accuracy, with the exception of H-VOR ≥2. The total VOMS score had the highest discriminative utility for singling out concussion in this population, with an AUC of 0.91 and an optimal cutoff score ≥8. This study also sought to determine the best combined VOMS discriminators of concussion in this population, similar to what Mucha et al[23] reported for adolescent athletes. The forward stepwise multivariate logistic regression retained vertical saccades ≥1 and H-VOR ≥2 as the strongest discriminators of concussion in the present sample of collegiate athletes. However, that 2-factor model's AUC (0.83) was less accurate than several individual VOMS items and the total VOMS score. Overall, these results support the utility of the VOMS as a tool for identifying concussion in collegiate athletes.

VOMS is recognized as a key component of a multidomain concussion evaluation.[13] Since being published in 2014, VOMS has become one of the primary tools for assessment of vestibular/oculomotor symptoms and dysfunction after concussion.[13,25] The results of the present study extend previous findings from Mucha et al[23] in adolescent athletes to a collegiate athlete population, supporting VOMS as a useful tool for identifying concussion—specifically, cutoffs for all VOMS symptom items ≥1, an increase when compared with cutoffs for adolescents in the Mucha et al study. Consequently, a score ≥1 on any VOMS item (with the exception of H-VOR ≥2) and ≥8 on the total VOMS could discriminate concussion in the current study of college-age athletes, providing intuitive and useful parameters to clinicians for singling out collegiate athletes with concussion.

NPC distance is a key component of oculomotor screening in concussion. In the Mucha et al[23] study, the authors reported that an NPC distance ≥5 cm increased the probability of a concussion by at least 34%. However, in the present study, NPC distance was not discriminative of concussion (Table 3), and both groups demonstrated an average NPC distance <5 cm (Table 2). Of note, the concussed group's NPC distance was much more variable than the control group's, with a standard deviation nearly double that of controls (5.0 vs 2.6). This variability in NPC distance in the concussed group may reflect the heterogeneity of this injury such that not all athletes experience convergence dysfunction after concussion. In other words, collegiate athletes may still be concussed despite NPC distance being under the cutoff value. Previous research has suggested that convergence insufficiency, defined as a receded NPC distance, is common and related to worse acute symptoms and prolonged recovery, but this research has been predominantly in children and adolescent athletes.[9,19,20,24,27] More research may be required to assess the utility of NPC distance for identifying concussion in collegiate athletes.

This study provides the first clinical cutoff for overall VOMS score with evidence that it is useful in identifying concussion in collegiate athletes. Specifically, an overall VOMS score ≥8 significantly discriminated concussion from control with 91% accuracy (Table 3). Furthermore, the total VOMS score had a slightly higher AUC than any individual VOMS item. This result may reflect the added benefit of considering oculomotor and vestibular

TABLE 3
Receiver Operating Characteristic AUCs for Identification of Concussion Versus Matched Control[a]

	AUC	95% CI	Cutoff	Youden Index, J
Smooth pursuit	0.90	0.86-0.93[b]	1	0.74
Horizontal saccade	0.90	0.86-0.93[b]	1	0.73
Vertical saccade	0.90	0.87-0.93[b]	1	0.75
Near point of convergence	0.90	0.87-0.94[b]	1	0.73
Near point of convergence, cm	0.51	0.46-0.57	4.5	0.12
VOR: horizontal	0.90	0.86-0.93[b]	2	0.72
VOR: vertical	0.90	0.87-0.93[b]	1	0.75
Visual-motion sensitivity	0.89	0.86-0.92	1	0.71
VOMS overall	0.91	0.88-0.94[b]	8	0.73

[a]AUC, area under the curve; VOMS, Vestibular/Ocular Motor Screening; VOR, vestibular/ocular reflex.
[b]Significant at $P < .05$.

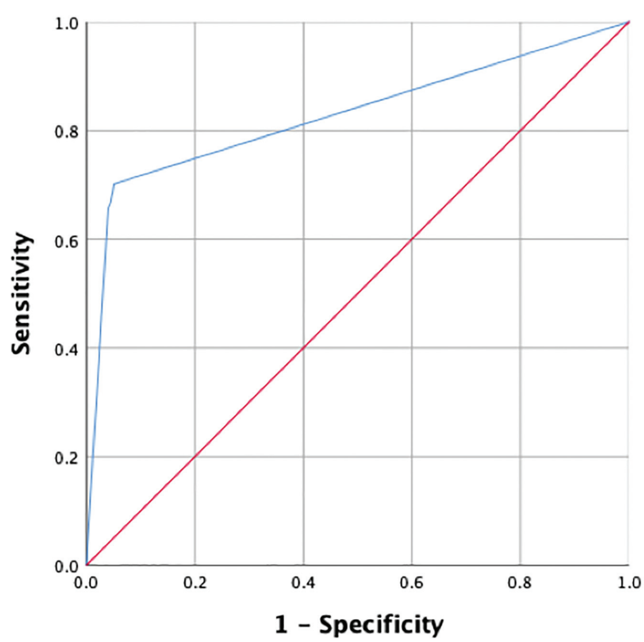

Figure 2. ROC analysis of a 2-factor VOMS model to identify concussion (n = 285) from control (n = 285) using 2 symptom scores (bent line): vertical saccades $\geq$1 and horizontal vestibular/ocular reflex $\geq$2. AUC = 0.83. The straight reference line indicates that AUC = 0.50 ($P < .001$). AUC, area under the curve; ROC, receiver operating characteristic; VOMS, Vestibular/Ocular Motor Screening.

dysfunction after concussion.[19] Physiologically, the oculomotor and vestibular systems are connected, and it is common for patients to experience both types of impairments and symptoms after concussion.[20] This relationship between these systems was highlighted in the regression model, which singled out the best discriminators of concussion using all VOMS item scores. Vertical saccades $\geq$1 and H-VOR $\geq$2 were the 2 most significant discriminators of concussion. This result reinforces the importance of the oculomotor and vestibular components of VOMS, as vertical saccades is primarily an oculomotor task whereas H-VOR is primarily a vestibular task.[23]

Limitations

This study has several limitations worth noting. The results were delimited to collegiate athletes who were evaluated within 3 days of injury. As such, it is unknown if the findings would be similar in different age groups or beyond the acute recovery period. A higher percentage of the concussed group in this study reported migraine history as compared with the control group. Although this result is in line with previous research on the association of migraine history and concussion, it could have affected the reporting of symptoms in the current study.[26] The groups were matched on age, sex, and concussion history, which may have inadvertently introduced selection bias in the sample. We were not able to control for position played in each sport, which could have affected the number of head impacts/exposures per participant. Finally, the data were collected at multiple sites from the NCAA-DoD CARE Consortium, which may have resulted in variability among test administrators. However, to mitigate this risk, all NCAA-DoD CARE Consortium investigators were trained to properly and consistently administer the VOMS before study initiation. Furthermore, having multiple sites improves the external validity of the results.

CONCLUSION

Vestibular and oculomotor screening, using tools such as VOMS, is a critical component of a multifaceted concussion evaluation. The results of this study suggest that individual VOMS items and an overall VOMS score are valid tools for identifying concussion in collegiate athletes within 3 days of injury. Clinicians should take into consideration oculomotor and vestibular items from the VOMS, as vertical saccades and H-VOR were the most robust discriminators of concussion among VOMS items. However, in contrast with previous research on adolescents, NPC distance was not a significant differentiator between concussion and control. Finally, all VOMS items had high discriminative utility, and the total VOMS score identified concussion at a higher rate than any VOMS item or the 2-factor model. The high discriminative utility of the VOMS tool, combined with the cutoff scores for total VOMS and each VOMS item, may help clinicians identify concussion in collegiate athletes in the first few days after injury.

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