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Vestibular/Ocular Motor Screening Assessment Outcomes After Sport-Related Concussion in High School and Collegiate Athletes

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Context: Vestibular and ocular motor assessment is an emerging clinical assessment for patients with sport-related concussion (SRC). The increased use of these assessments by clinicians calls for the examination of outcomes that may affect clinical practice.

Objective: To compare vestibular and ocular motor impairments in high school and collegiate athletes within 72 hours of SRC and examine the distribution of impairments in these populations based on pre-established clinical cutoff scores.

Design: Cross-sectional study.

Setting: High school and collegiate athletics.

Patients or Other Participants: Data were collected from 110 athletes (high school: n = 47, age = 15.40 ± 1.35 years; college: n = 63, age = 19.46 ± 1.28 years) within 72 hours of sustaining an SRC.

Main Outcome Measure(s): Total and change scores were calculated for the Vestibular/Ocular Motor Screening (VOMS) tool, along with average near point of convergence (NPC) distance. Separate Mann-Whitney *U* tests were used to compare group differences, and χ^2 analyses were used to examine the proportion of athletes with scores greater than clinical cutoff scores for all VOMS outputs. The α level was set a priori at .05.

Results: No differences were found between high school and collegiate athletes for VOMS total and change scores and NPC distance. A larger proportion of the sample had scores greater than the cutoff for all total scores ($P < .001$) and change scores in horizontal vestibulo-ocular reflex (59.01%; $P < .001$), vertical vestibulo-ocular reflex (60.91%; $P < .001$), and visual motion sensitivity (60.91%; $P < .001$). However, a larger proportion demonstrated smooth pursuit change scores (85.45%; $P < .001$) and NPC distances (73.64%; $P = .01$) that were less than the cutoff scores.

Conclusions: During the acute phase of SRC, high school and collegiate athletes presented with similar vestibular and ocular motor impairments as measured using the VOMS, but vestibular tasks appeared to cause greater symptom provocation. Lastly, VOMS change scores may offer more clinical utility compared with total scores in assessing specific impairments after SRC.

Key Words: multifaceted assessment, total scores, change scores, age

Key Points

- During the acute phase of sport-related concussion, high school and collegiate athletes presented with similar Vestibular/Ocular Motor Screening total and change scores.
- Athletes with concussion tended to experience greater symptom provocation during vestibular tasks than during ocular motor tasks.
- Vestibular/Ocular Motor Screening change scores may provide additional clinical information when assessing patients with acute vestibular and ocular motor impairments by identifying tasks that have the greatest effects on symptoms.

Sport-related concussions (SRCs) manifest in a wide array of clinical symptoms that are managed using a multifaceted approach consisting of a clinical interview, graded symptom checklist, cognitive testing, and balance assessment.[1] Vestibular and ocular motor testing is the most recent addition to this multimodal approach and is likely a response to the increased prevalence of vestibular dysfunctions after SRC.[2–5] In the clinical setting, these dysfunctions have commonly been assessed using balance testing. However, the focus on testing the vestibular and ocular motor systems has led to the addition of assessments focusing on athlete symptoms commonly linked to system impairments.[1,6] Through this shift in clinical practice, dizziness has been identified as one of the leading vestibular and ocular motor symptoms after SRC in both high school and collegiate athletes and may be a predictor of prolonged recovery.[2,4,7,8] The introduction of vestibular and ocular motor testing into the multifaceted paradigm enables clinicians to conduct a more detailed and thorough evaluation.

The Vestibular/Ocular Motor Screening (VOMS) assessment is used to evaluate vestibular and ocular motor

symptoms (ie, headache, dizziness, nausea, fogginess) after SRC. The VOMS consists of 8 tasks designed to test various aspects of vestibular and ocular motor control and is interpreted based on symptom outcomes using total and change scores.[9] Clinical cutoff scores based on the total scores have been established to aid in identifying athletes with concussion.[10] However, primarily using VOMS total scores to identify concussions may limit clinicians' interpretations, especially when considering that greater symptom provocation (ie, change scores) on the VOMS has been associated with SRC recovery delays.[11–13]

Numerous authors[2,10,13,14] have examined VOMS outcomes and identified a range of symptom-provocation patterns in athletes with SRC. Along with this diversity in VOMS performance, researchers[2,10,13–15] have assessed athletes at various stages of recovery (ie, acute, subacute, and prolonged recovery). The need for efficient evaluations of the vestibular and ocular motor systems has positioned the VOMS as a primary assessment for clinicians to use immediately after athletes sustain SRC. Unfortunately, few investigators have focused on the VOMS assessment exclusively during the acute phase of recovery ($\leq$72 hours). The Concussion Assessment, Research, and Education Consortium,[15] seeking to optimize the multifaceted SRC assessment process in the collegiate setting, did identify the VOMS as an emerging clinical assessment and included it in their analyses. The VOMS demonstrated moderate to strong sensitivity during sideline (0–1.25 hours), postevent (1.25–24 hours), and clinic (24–72 hours) evaluations when coupled with baseline evaluations taken in the same competitive season.[15] These results showed the efficacy of the VOMS during the acute phase of recovery and supported its inclusion in the SRC assessment paradigm. However, the researchers[15] did not investigate the VOMS in high school athletes and did not examine age differences in vestibular and ocular impairments after SRC.

Age has been reported to influence several aspects of the SRC assessment, including cognitive testing,[16] symptom reporting,[17] and balance.[16,18] Structural and cognitive maturation of the brain throughout adolescence and early adulthood is believed to be a driving factor in cognitive differences between high school and collegiate athletes post-SRC, but the vestibular and ocular motor systems tend to fully mature by the age of 18 years.[19–21] However, Benedict et al[18] reported that age may be more associated with subjective or self-reported SRC assessments than with objective measures, which is supported by the fact that high school athletes described more postconcussion symptoms than did collegiate athletes.[17] Given that the VOMS is a subjective measure of vestibular and ocular motor impairment that relies on symptom reporting, this association may be present despite the brain being structurally mature.

The integration of vestibular and ocular motor testing into the acute SRC assessment paradigm calls for further investigation into the VOMS assessment. Collegiate and high school athletes have already been shown to differ on multiple components of the multifaceted assessment process after SRC, and in the context of the VOMS as an emerging clinical tool, it is important to continue this examination. Therefore, the primary purpose of our study was to compare vestibular and ocular motor impairments in high school and collegiate athletes within 72 hours of SRC. We hypothesized that high school athletes would present with greater VOMS total and change scores during the acute phase of SRC compared with collegiate athletes. A secondary purpose was to examine the distribution of impairments based on the predetermined clinical cutoff scores using VOMS total and change scores.

METHODS

Research Design and Participants

A cross-sectional study design was used to compare vestibular and ocular motor symptom provocation between high school and collegiate athletes with SRC. Participants were recruited from several high schools and 2 universities in the Midwest region of the United States. High school and collegiate athletes were included in the study if they were between the ages of 13 and 25 years, had an SRC diagnosed by a certified athletic trainer or physician, and completed the VOMS within 72 hours of injury. Athletes who did not speak English, who were currently taking central nervous system medication, or who had sustained a nonsport-related concussion were excluded from the study.

Definition of SRC

Sport-related concussion was defined as a traumatic brain injury induced by biomechanical forces that results in clinical signs and symptoms.[1] All SRCs were diagnosed by health care providers based on (1) the observed or reported mechanism of injury and (2) the presence of $\geq$1 of the following: (a) on-field signs (eg, disorientation or confusion, loss of consciousness, balance difficulties, (b) symptoms (eg, headache, dizziness, nausea), or (c) any impairment(s) on sideline evaluations (eg, Sport Concussion Assessment Tool).

Instruments

The VOMS comprises several domains: (1) pre-VOMS administration (baseline) symptoms, (2) smooth pursuits, (3) horizontal saccades, (4) vertical saccades, (5) near point convergence (NPC) symptoms, (6) NPC distance (in centimeters), (7) horizontal vestibulo-ocular reflex (VOR), (8) vertical VOR, and (9) visual motion sensitivity (VMS). We refer to baseline symptoms as pre-VOMS administration symptoms for the remainder of the paper. Before we administered any of the vestibular and ocular motor domains, the participants rated pre-VOMS administration symptoms of headache, dizziness, nausea, and fogginess on an 11-point Likert scale, ranging from 0 (*none*) to 10 (*severe*). After the administration of each subsequent VOMS component, participants rated their symptoms of headache, dizziness, nausea, and fogginess. The VOMS outcomes were recorded as total scores, change scores, and NPC distance (in centimeters). The NPC distance was measured from the nose to the target and marked as 0 cm if diplopia was not induced.[22]

Along with being a sensitive measure of vestibular and ocular motor impairments during the acute phase of SRC,[15] the VOMS has high internal consistency in both youth (Cronbach $\alpha = 0.97$)[23] and collegiate (Cronbach $\alpha = 0.97$) athletes.[9] In addition, the NPC procedures used in the VOMS are reliable (intraclass correlation coefficient range, 0.95–0.98).[10,22] Clinical cutoff scores have been established for the VOMS using total scores to aid in the identification

Table 1. Descriptive Data for High School and Collegiate Athletes With Sport-Related Concussion

Characteristic	Athletes			*P* Value[a]
	High School (n = 47)	Collegiate (n = 63)	Total (N = 110)	
	Mean ± SD			
Age	15.40 ± 1.35	19.46 ± 1.28	18.01 ± 2.34	NA
Time to assessment, d	2.32 ± 0.75	2.17 ± 0.83	2.24 ± 0.80	.84[b]
	No. (%)			
Sex				.24
Male	33 (70.2)	37 (58.7)	70 (63.6)	
Female	14 (29.8)	26 (41.3)	40 (36.4)	
Previous history of concussion				.05
Yes	14 (29.8)	31 (49.2)	45 (40.9)	
No	33 (70.2)	32 (50.8)	65 (59.1)	
History of headaches or migraines				.07
Yes	6 (12.8)	2 (3.2)	8 (7.3)	
No	41 (87.2)	61 (96.8)	102 (92.7)	
Learning disability or attention-deficit/hyperactivity disorder				.67
Yes	2 (4.3)	5 (7.9)	7 (6.4)	
No	45 (95.7)	58 (92.1)	103 (93.6)	
Depression or anxiety (or both)				>.99
Yes	5 (10.6)	8 (12.7)	13 (11.8)	
No	42 (89.4)	55 (87.3)	97 (88.2)	
Sport				NA
Basketball	7 (14.9)	5 (7.9)	12 (10.9)	
Cheerleading	3 (6.4)	2 (3.2)	5 (4.5)	
Crew	NA	2 (3.2)	2 (1.8)	
Field hockey	NA	2 (3.2)	2 (1.8)	
Football	22 (46.8)	18 (28.6)	40 (36.4)	
Ice hockey	1 (2.1)	NA	1 (0.9)	
Lacrosse	2 (4.3)	4 (6.3)	6 (5.5)	
Nontraditional	1 (2.1)	7 (11.1)	8 (7.3)	
Rugby	NA	4 (6.3)	4 (3.6)	
Soccer	3 (6.4)	7 (11.1)	10 (9.1)	
Softball	1 (2.1)	1 (1.6)	2 (1.8)	
Swimming	2 (4.3)	1 (1.6)	3 (2.7)	
Tennis	1 (2.1)	1 (1.6)	2 (1.8)	
Track and field	2 (4.3)	2 (3.2)	4 (3.6)	
Volleyball	1 (2.1)	1 (1.6)	2 (1.8)	
Wrestling	1 (2.1)	6 (9.5)	7 (6.4)	

Abbreviation: NA, not applicable.

[a] The χ^2 test of independence was used to determine group equivalency.

[b] Independent-samples *t* test was used to determine group equivalency.

[c] Percentages were rounded, so the sum may not equal 100%.

of individuals with concussion. Specifically, a total score for a VOMS component of $\geq$2 and an NPC distance of $\geq$5 cm increased the probability of identifying athletes with concussions by 50% and 38%, respectively.[10]

Procedures

Before enrollment of participants, the study was approved by the Michigan State University Institutional Review Board. All participants who were minors and their parents or guardians provided written informed assent and consent, respectively, and all adult participants provided written informed consent. Participants were administered the VOMS within 72 hours of sustaining an SRC. Each concussive injury was assessed and managed by a certified athletic trainer or team physician at the respective institution. All testing was administered by a trained researcher and took place in the athletic training facility or designated testing room at each school or university.

Statistical Analysis

We used descriptive statistics (frequencies, means, SDs) to describe the sample. The χ^2 test of independence and independent-samples *t* test were conducted for all descriptive variables to ensure group equivalency. Total VOMS scores were calculated for each VOMS component by summing each symptom score for headache, dizziness, nausea, and fogginess. To examine symptom provocation of individual components, we obtained change scores by subtracting the pre-VOMS administration score from the component total symptom score. For example, if a participant had a total pre-VOMS symptom score of 5 and a total smooth-pursuit score of 7, the change score would be 2 for smooth pursuits. If a VOMS component change score was 0 or a negative value (ie, the participant's total symptom score improved), the change was reported as 0 for no symptom provocation.[2] Lastly, NPC distance was calculated by averaging the distances of 3 trials in centimeters.

Table 2. Comparison of Vestibular/Ocular Motor Screening Tool Total and Change Scores in High School and Collegiate Athletes With Sport-Related Concussion

Variable	High School Athletes		Collegiate Athletes		*U* Value	*z* Value	*P* Value
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)			
Before Vestibular/Ocular Motor Screening tool							
Total	8.28 ± 6.92	6.00 (11.00)	7.79 ± 6.01	6.00 (9.25)	1460.50	−0.12	.90
Change[a]	NA	NA	NA	NA	NA	NA	NA
Smooth pursuits							
Total	8.87 ± 7.52	7.00 (11.00)	8.26 ± 6.36	6.00 (9.50)	1457.50	−0.14	.89
Change[a]	0.68 ± 1.16	0.00 (1.00)	0.60 ± 0.91	0.00 (1.00)	1441.50	−0.27	.79
Horizontal saccades							
Total	9.85 ± 8.13	7.00 (12.00)	9.05 ± 6.82	7.00 (11.00)	1434.50	−0.28	.78
Change	1.64 ± 2.03	1.00 (3.00)	1.34 ± 1.58	1.00 (2.00)	1409.50	−0.45	.66
Vertical saccades							
Total	9.96 ± 8.20	8.00 (12.00)	9.35 ± 7.03	8.00 (11.25)	1456.50	−0.15	.89
Change	1.83 ± 2.26	1.00 (3.00)	1.65 ± 1.87	1.00 (3.00)	1454.00	−0.17	.87
Near point of convergence symptoms							
Total	10.04 ± 8.56	7.00 (12.00)	8.73 ± 7.16	7.00 (12.25)	1360.00	−0.56	.55
Change	2.28 ± 3.03	1.00 (3.00)	1.25 ± 1.64	1.00 (2.00)	1177.00	−1.79	.07
Horizontal vestibulo-ocular reflex							
Total	11.33 ± 8.66	11.00 (14.00)	9.73 ± 7.47	7.50 (12.00)	1347.50	−0.81	.42
Change	3.12 ± 3.39	2.00 (4.00)	2.21 ± 2.44	2.00 (2.25)	1256.50	−1.38	.17
Vertical vestibulo-ocular reflex							
Total	11.36 ± 8.71	10.00 (13.00)	9.77 ± 7.50	7.00 (13.00)	1360.00	−0.73	.45
Change	3.13 ± 3.42	2.00 (3.00)	2.26 ± 2.56	2.00 (3.00)	1289.50	−1.16	.24
Visual motion sensitivity							
Total	11.85 ± 9.15	11.00 (12.00)	10.47 ± 7.96	8.00 (10.75)	1377.50	−0.62	.53
Change	3.60 ± 3.79	2.00 (4.00)	2.76 ± 3.19	2.00 (4.00)	1260.00	−1.35	.18

Abbreviations: IQR, interquartile range; NA, not applicable.

[a] Change scores indicate symptom provocation after the Vestibular/Ocular Motor Screening tool components.

The data were not normally distributed; therefore, the Mann-Whitney *U* test was performed to compare the differences in total and change scores between high school and collegiate athletes. The independent variable was group (high school, collegiate), and the dependent variables were VOMS total and change scores. We conducted the χ^2 goodness-of-fit test to examine the distribution of the sample with scores greater than the clinical cutoff scores for total scores, change scores, and average NPC distance. All analyses were carried out using SPSS (version 25; IBM Corp). The α level was set a priori at .05.

RESULTS

Characteristics

A total of 110 athletes (high school: n = 47, age = 15.40 ± 1.35 years; college: n = 63, age = 19.46 ± 1.28 years) completed the VOMS assessment within 72 hours of sustaining an SRC. Most of the sample was male (63.6%) and played football (36.4%). Participants were tested an average of 2 days postinjury. A full summary (frequencies, means, SDs) of the descriptive variables and group equivalency analyses is presented in Table 1.

Comparisons of VOMS Outcomes in High School and Collegiate Athletes

No differences were found between high school and collegiate athletes for VOMS total scores and VOMS change scores (Table 2). Similarly, no group differences were observed for average NPC distance (high school: 4.53 ± 4.74, collegiate: 3.48 ± 5.66; $U = 1202.50$, $z = -1.72$, $P = .09$).

The VOMS Outcomes in Athletes During the Acute Phase of SRC

A significant proportion of our participants achieved total scores greater than the clinical cutoff score (≥2) for all VOMS components ($P < .001$; Figure 1). However, when examining change scores, we noted mixed results, with symptoms being provoked more by the vestibular tasks (Figure 2). Specifically, we identified more athletes whose symptom-provocation scores were greater than the clinical cutoff score for the horizontal VOR (n = 65 [59.09%]; $\chi^2_{1,110} = 20.77$, $P < .001$), vertical VOR (n = 67 [60.91%]; $\chi^2_{1,110} = 24.50$, $P < .001$), and VMS (n = 67 [60.91%]; $\chi^2_{1,110} = 24.50$, $P < .001$) VOMS components. Conversely, more athletes had symptom-provocation scores that were less than the clinical cutoff scores for smooth pursuits (n = 94 [85.45%]; $\chi^2_{1,110} = 25.66$, $P < .001$) and average NPC distance (n = 81 [73.64%]; $\chi^2_{1,110} = 6.32$, $P = .01$). Lastly, no differences occurred in the proportion of athletes whose scores were greater than the cutoff score for horizontal saccades (score ≥ 2: n = 37 [33.64%]; score < 2: n = 73 [66.36%]; $\chi^2_{1,110} = 0.89$, $P = .35$), vertical saccades (score ≥ 2: n = 44 [40.00%]; score < 2: n = 66 [66.00%]; $\chi^2_{1,110} = 0.19$, $P = .67$), and NPC symptoms (score ≥ 2: n = 41 [37.27%]; score < 2: n = 68 [61.82%]; $\chi^2_{1,110} = 0.01$, $P = .93$).

DISCUSSION

We found that high school and collegiate athletes presented similarly based on VOMS total scores, change scores, and NPC distance during the acute phase of SRC, distinguishing vestibular and ocular motor assessment from other hallmarks of the multifaceted assessment paradigm

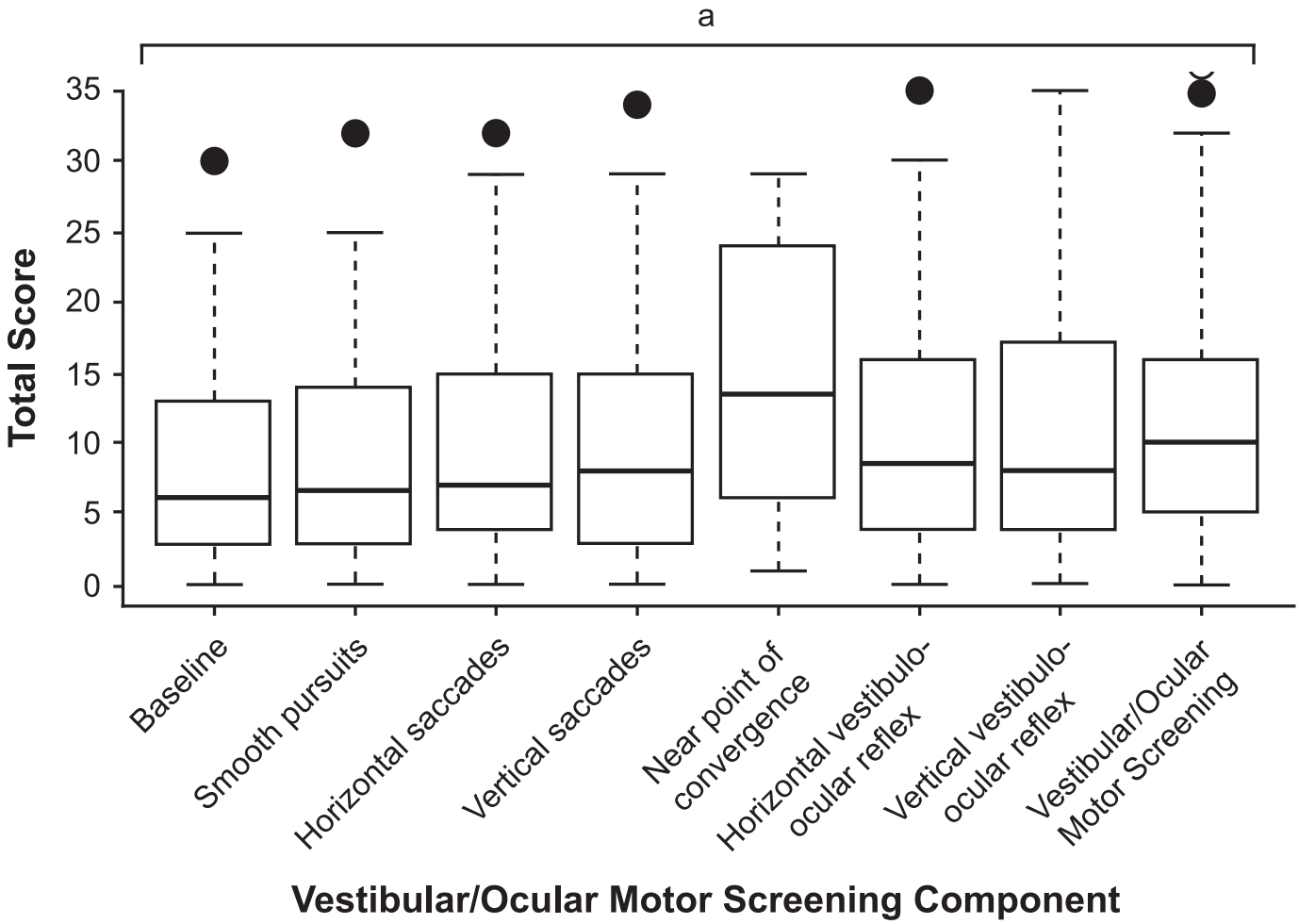

Figure 1. A significant proportion of athletes with concussion demonstrated total scores greater than the clinical cutoff score (≥2) for all Vestibular/Ocular Motor Screening tool components. The boxes represent the 25th and 75th percentiles of the interquartile range, the horizontal line represents the median, the whiskers are the range of the data, and the circles are the outliers. [a] $P < .001$.

that have demonstrated differences between these groups.[16–18] In addition, participants consistently displayed VOMS total scores that were greater than previously established cutoff scores; however, change scores varied.[10] Specifically, the symptom provocation of approximately 60% of participants was greater than the cutoff score for horizontal VOR, vertical VOR, and VMS. Conversely, 73.64% to 85.45% of participants did not experience symptom provocation great enough to exceed the cutoff scores for smooth pursuits and NPC distance demonstrating that VOMS change scores may offer a more detailed picture of how the vestibular and ocular motor systems are affected postinjury.

Previous researchers[3–5,13,24–26] have reported vestibular and ocular motor deficiencies in both adolescents and adults after SRC. However, a direct comparison between high school and collegiate athletes was needed to determine the extent of the acute impairments in each population. We observed that high school and collegiate athletes experienced similar levels of impairment after SRC, as determined using VOMS outcomes. It appears that the association between age and subjective SRC assessments may not be a factor when administering the VOMS postinjury, although it uses self-reported symptoms to evaluate impairments.[18] This differs from other aspects of the multifaceted assessment, such as cognitive testing and symptom reporting, that have demonstrated this association between high school and collegiate athletes.[16–18]

A possible explanation could be that these assessments, such as cognition, are tethered to areas of the brain (eg, frontal lobe) that continue to develop until athletes are roughly aged 25 years,[27] whereas the vestibular and ocular motor systems are most likely fully developed by the time athletes reach the collegiate level. Therefore, clinicians who frequently work with high school and collegiate athletes may be able to design similar vestibular and ocular motor rehabilitation programs regardless of their setting. Furthermore, given that the acute presentations of high school and collegiate athletes appear to be similar, it could be beneficial for clinicians to interpret the VOMS consistently in each setting.

The VOMS produces both total and change scores that clinicians can use for interpretations of the vestibular and ocular motor systems after SRC. Given that the primary goal of the multifaceted assessment is to diagnose SRC, cutoff scores for the VOMS components were established using total scores to aid in identifying athletes with concussion.[10] The focus on total scores to simply identify injured individuals may narrow clinicians' interpretation of the VOMS, leaving them susceptible to missing clinically

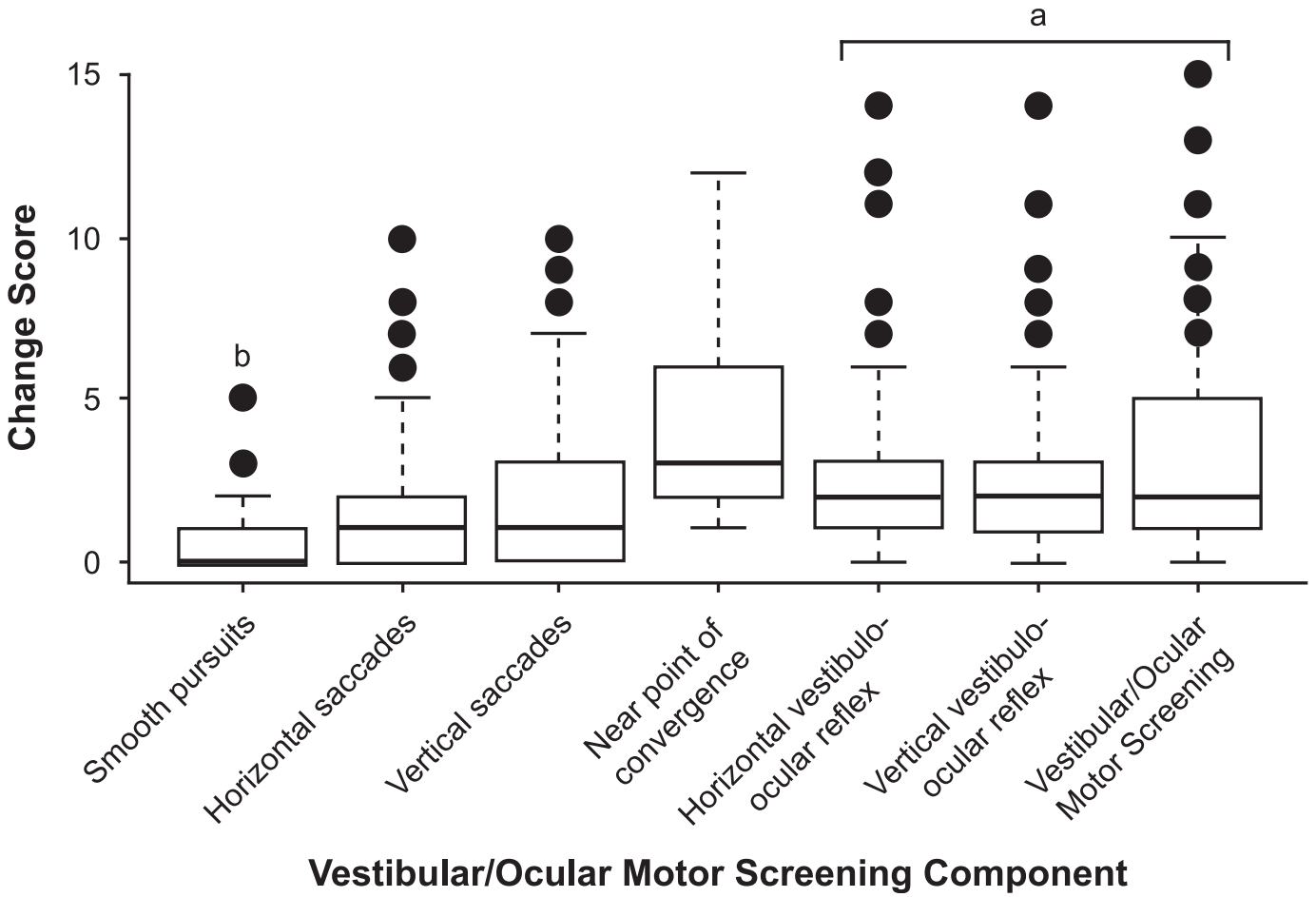

Figure 2. The distributions of injured athletes' Vestibular/Ocular Motor Screening tool change scores varied with vestibular tasks, resulting in a greater proportion presenting with scores higher than the clinical cutoff score (≥2), while ocular motor tasks led to either no difference or a larger proportion presenting with scores less than the cutoff score, including the near point of convergence distance (≥5 cm, $P = .01$). Boxes represent the 25th and 75th percentiles of the interquartile range, the horizontal line represents the median, the whiskers are the range of the data, and the circles are the outliers. [a] Score < 2 ($P < .001$). [b] Score ≥ 2 ($P < .001$).

relevant information.[2] Specifically, the individual influence of each VOMS component on athletes' symptoms provided by the change scores may offer a more direct avenue for identifying specific impairments.[2] We demonstrated this in the current findings by applying the cutoff scores to both total and change scores and examining the proportion of athletes presenting greater scores for each; all total scores were greater than the clinical cutoff, while the change scores varied. The variations in change scores revealed that the athletes with SRC had more adverse reactions to the vestibular components of the VOMS than to the ocular motor components. This information can give clinicians a better representation of how vestibular and ocular motor tasks are affecting the athlete when they assess SRC acutely, and it can be used to guide rehabilitative efforts or referral to specialized postinjury care.

This study had limitations. First, the sample of convenience resulted in unequal group sizes; thus, the analyses may have been underpowered to detect smaller effects. Baseline VOMS measurements were not collected, making it difficult to know whether abnormalities associated with the VOMS were indeed a result of the SRC. A detailed past medical history was not collected, and whether any of the participants had underlying vestibular or ocular motor disorders or dysfunctions or a history of motion sickness is unknown. Lastly, VOMS protocol dictates that the tasks be conducted in a specific order, and to ensure consistency with clinical administration, we did not counterbalance the order of the components. However, the test order for the VOMS has been shown to not affect outcome scores in high school athletes.[28]

CONCLUSIONS

Our findings did not support the hypothesis that high school athletes would present with worse outcomes on the VOMS compared with collegiate athletes after SRC, unlike other hallmarks of the assessment paradigm, such as cognition and symptom reporting. This highlights the potential for consistent rehabilitative care postinjury in each setting. However, the vestibular components of the VOMS appeared to result in greater symptom provocation compared with the ocular motor components. Therefore, change scores may offer clinicians a more detailed look at vestibular and ocular motor deficits immediately after SRC. Future researchers should continue to explore the effect of age on VOMS outcomes, especially in youth athletes who have not reached full development. In addition, more demographic distinctions and preexisting conditions should

be examined to determine their influence on the VOMS. Overall, during the acute phase of SRC, clinicians working with high school and collegiate athletes should assess vestibular and ocular motor impairments immediately after a concussive incident to determine if advanced treatment is warranted.

REFERENCES

1. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th International Conference on Concussion in Sport held in Berlin, October 2016. *Br J Sports Med*. 2017;51(11):838–847. doi:10.1136/bjsports-2017-097699
2. Elbin RJ, Sufrinko A, Anderson MN, et al. Prospective changes in vestibular and ocular motor impairment after concussion. *J Neurol Phys Ther*. 2018;42(3):142–148. doi:10.1097/NPT.0000000000000230
3. Ellis MJ, Cordingley D, Vis S, Reimer K, Leiter J, Russell K. Vestibulo-ocular dysfunction in pediatric sports-related concussion. *J Neurosurg Pediatr*. 2015;16(3):248–255. doi:10.3171/2015.1.PEDS14524
4. Master CL, Master SR, Wiebe DJ, et al. Vision and vestibular system dysfunction predicts prolonged concussion recovery in children. *Clin J Sport Med*. 2018;28(2):139–145. doi:10.1097/JSM.0000000000000507
5. Master CL, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. *Clin Pediatr (Phila)*. 2016;55(3):260–267. doi:10.1177/0009922815594367
6. Furman JM, Marcus DA. Migraine and motion sensitivity. *Continuum (Minneap Minn)*. 2012;18(5 Neuro-otology):1102–1117. doi:10.1212/01.CON.0000421621.18407.96
7. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE. Epidemiology of concussion in collegiate and high school football players. *Am J Sports Med*. 2000;28(5):643–650. doi:10.1177/03635465000280050401
8. Lau B, Lovell MR, Collins MW, Pardini J. Neurocognitive and symptom predictors of recovery in high school athletes. *Clin J Sport Med*. 2009;19(3):216–221. doi:10.1097/JSM.0b013e31819d6edb
9. Kontos AP, Sufrinko A, Elbin R, Puskar A, Collins MW. Reliability and associated risk factors for performance on the Vestibular/Ocular Motor Screening (VOMS) tool in healthy collegiate athletes. *Am J Sports Med*. 2016;44(6):1400–1406. doi:10.1177/0363546516632754
10. Mucha A, Collins MW, Elbin R, et al. A brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med*. 2014;42(10):2479–2486. doi:10.1177/0363546514543775
11. Meehan WP III, O'Brien MJ, Geminiani E, Mannix R. Initial symptom burden predicts duration of symptoms after concussion. *J Sci Med Sport*. 2016;19(9):722–725. doi:10.1016/j.jsams.2015.12.002
12. Meehan WP III, Mannix RC, Stracciolini A, Elbin R, Collins MW. Symptom severity predicts prolonged recovery after sport-related concussion, but age and amnesia do not. *J Pediatr*. 2013;163(3):721–725. doi:10.1016/j.jpeds.2013.03.012
13. Anzalone AJ, Blueitt D, Case T, et al. A positive Vestibular/Ocular Motor Screening (VOMS) is associated with increased recovery time after sports-related concussion in youth and adolescent athletes. *Am J Sports Med*. 2017;45(2):474–479. doi:10.1177/0363546516668624
14. Womble MN, McAllister-Deitrick J, Marchetti GF, et al. Risk factors for vestibular and oculomotor outcomes after sport-related concussion. *Clin J Sport Med*. 2021;31(4):e193–e199. doi:10.1097/JSM.0000000000000761
15. Broglio SP, Harezlak J, Katz B, et al; CARE Consortium Investigators. Acute sport concussion assessment optimization: a prospective assessment from the CARE Consortium. *Sports Med*. 2019;49(12):1977–1987. doi:10.1007/s40279-019-01155-0
16. Covassin T, Elbin R, Harris W, Parker T, Kontos A. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med*. 2012;40(6):1303–1312. doi:10.1177/0363546512444554
17. Kerr ZY, Zuckerman SL, Wasserman EB, Covassin T, Djoko A, Dompier TP. Concussion symptoms and return to play time in youth, high school, and college American football athletes. *JAMA Pediatr*. 2016;170(7):647–653. doi:10.1001/jamapediatrics.2016.0073
18. Benedict PA, Baner NV, Harrold GK, et al. Gender and age predict outcomes of cognitive, balance and vision testing in a multidisciplinary concussion center. *J Neurol Sci*. 2015;353(1–2):111–115. doi:10.1016/j.jns.2015.04.029
19. Luna B, Velanova K, Geier CF. Development of eye-movement control. *Brain Cogn*. 2008;68(3):293–308. doi:10.1016/j.bandc.2008.08.019
20. Steindl R, Kunz K, Schrott-Fischer A, Scholtz A. Effect of age and sex on maturation of sensory systems and balance control. *Dev Med Child Neurol*. 2006;48(6):477–482. doi:10.1017/S0012162206001022
21. Pritcher MR, Whitney SL, Marchetti GF, Furman JM. The influence of age and vestibular disorders on gaze stabilization: a pilot study. *Otol Neurotol*. 2008;29(7):982–988. doi:10.1097/MAO.0b013e31818457fb
22. Pearce KL, Sufrinko A, Lau BC, Henry L, Collins MW, Kontos AP. Near point of convergence after a sport-related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. *Am J Sports Med*. 2015;43(12):3055–3061. doi:10.1177/0363546515606430
23. Moran RN, Covassin T, Elbin R, Gould D, Nogle S. Reliability and normative reference values for the Vestibular/Ocular Motor Screening (VOMS) tool in youth athletes. *Am J Sports Med*. 2018;46(6):1475–1480. doi:10.1177/0363546518756979
24. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han M, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. *Optometry*. 2007;78(4):155–161. doi:10.1016/j.optm.2006.11.011
25. Corwin DJ, Wiebe DJ, Zonfrillo MR, et al. Vestibular deficits following youth concussion. *J Pediatr*. 2015;166(5):1221–1225. doi:10.1016/j.jpeds.2015.01.039
26. Galetta KM, Brandes LE, Maki K, et al. The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. *J Neurol Sci*. 2011;309(1-2):34–39. doi:10.1016/j.jns.2011.07.039
27. Sowell ER, Thompson PM, Holmes CJ, Jernigan TL, Toga AW. In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nat Neurosci*. 1999;2(10):859–861. doi:10.1038/13154
28. D'Amico NR, Elbin R, Sufrinko A, et al. Test order does not affect Vestibular/Ocular Motor Screening item scores in high school athletes. *Clin J Sport Med*. 2021;31(5):e240–d244. doi:10.1097/JSM.0000000000000776

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