

Reliability and Associated Risk Factors for Performance on the Vestibular/Ocular Motor Screening (VOMS) Tool in Healthy Collegiate Athletes

Anthony P. Kontos,^{*,†} PhD, Alicia Sufrinko,[†] PhD, R.J. Elbin,[‡] PhD,
Alicia Puskas,[†] PsyD, and Michael W. Collins,[†] PhD

Investigation performed at the University of Pittsburgh, Pittsburgh, Pennsylvania, USA

Background: The Vestibular/Ocular Motor Screening (VOMS) is a newly developed screening tool that evaluates vestibular and ocular motor symptom (eg, headache, dizziness, nausea, foggiess) provocation after a sport-related concussion. Baseline data on the VOMS are needed to extend the application of this measure to broad age groups and to document normal variations in performance.

Purpose: The primary purpose of this study was to examine the internal consistency of the VOMS in a large sample of healthy, nonconcussed collegiate athletes. The secondary purpose was to investigate the effects of patient sex and history of motion sickness, migraines, and concussions on baseline VOMS scores.

Study Design: Cohort study; Level of evidence, 2.

Methods: A total of 263 National Collegiate Athletic Association Division I athletes (mean \pm SD age, 19.85 \pm 1.35 years) completed self-reported demographic and medical history at preseason physical examinations and baseline screening. Internal consistency of the VOMS was assessed with Cronbach α . A series of univariate nonparametric tests (χ^2 with odds ratios [ORs] and 95% CIs) were used to examine the associations among medical history risk factors and VOMS clinical cutoff scores (score of ≥ 2 for any individual VOMS symptom, near point of convergence [NPC] distance of ≥ 5 cm), with higher scores representing greater symptom provocation.

Results: Internal consistency of the VOMS was high (Cronbach α = .97), and 89% of athletes scored below cutoff levels (ie, 11% false-positive rate). Female athletes (OR, 2.99 [95% CI, 1.34-6.70]; P = .006) and those with a personal history of motion sickness (OR, 7.73 [95% CI, 1.94-30.75]; P = .009) were more likely to have ≥ 1 VOMS scores above cutoff levels. No risk factors were associated with increased odds of an abnormal NPC distance.

Conclusion: The VOMS possesses internal consistency and an acceptable false-positive rate among healthy Division I collegiate student-athletes. Female sex and a history of motion sickness were risk factors for VOMS scores above clinical cutoff levels among healthy collegiate student-athletes. Results support a comprehensive baseline evaluation approach that includes an assessment of premorbid vestibular and oculomotor symptoms.

Keywords: college; concussion; baseline testing; vestibular; ocular motor

A sport-related concussion (SRC) is a heterogeneous injury characterized by a wide variety of symptoms and impairments that requires a multifaceted assessment and management approach. This approach includes a physical examination, clinical interview, symptom assessment, as well as neurocognitive and balance tests.²⁹ In addition to this assessment battery, recent advances in clinical research have emphasized the need to assess the integrity and function of the vestibular system, as 40% and 50% of athletes with an SRC report balance

dysfunction and dizziness, respectively.³¹ Balance deficits and reports of dizziness likely reflect underlying impairments of the vestibular system (eg, vestibulo-ocular and vestibulospinal) of the brain.¹⁸ The vestibular system is a complex sensory network that provides a subjective sense of self-motion and orientation that is vital to integrating sensory input and generating appropriate or accurate behaviors.¹² The presence of vestibulo-ocular dysfunction, which is linked to problems with gaze stability and visual motion sensitivity (VMS), has also been documented after an SRC.^{10,31} Assessing the vestibular system has traditionally involved specialized, sophisticated, and expensive testing equipment and has required the expertise of a trained clinician, none of which are readily available for the majority of clinicians who provide care for

athletes with an SRC. Within the context of these practical challenges, there is a need to create screening instruments that help to initially assess the vestibulo-ocular system and to provide information as to whether further evaluation and treatment needs are indicated.

The Vestibular/Ocular Motor Screening (VOMS) is a newly developed screening tool that evaluates vestibular and ocular motor symptom (eg, headache, dizziness, nausea, foggiess) provocation after an SRC. Items on the VOMS include smooth pursuits, saccades, vestibular ocular reflex (VOR), VMS, and near point of convergence (NPC) distance.³¹ Previous research by Mucha et al³¹ utilized the VOMS in a clinical sample of athletes with an SRC and matched nonconcussed controls. These researchers reported that over 60% of patients with an SRC experienced symptom provocation on ≥ 1 VOMS items, and they also derived clinical cutoff scores for this measure (ie, symptom score of ≥ 2 on any VOMS item).³¹ Nonconcussed controls did not demonstrate symptom provocation after the completion of the VOMS, suggesting that this measure has a low false-positive rate.³¹ Further, receiver operating characteristic curves in this study supported a model including the VOR, VMS, NPC distance, and age that resulted in a high predicted probability (area under the curve = 0.89) for identifying concussed patients. Although these data are the first to document the clinical value of this new screening measure, baseline data on the VOMS were not gathered in the concussed sample. In addition, the mean age for the control group used in the Mucha et al³¹ study was approximately 12 years. Additional baseline data on the VOMS in older athlete populations are needed to extend the application of this measure to other athlete age groups and to document normal variations in performance on this measure. These data will further help to inform the clinical utility of this tool.

In conjunction with gathering baseline data, factors that may negatively influence vestibular and oculomotor function warrant examination. Specifically, motion sickness susceptibility,³² migraines,² and anxiety⁴³ have been associated with decreased vestibular system functioning. Moreover, female sex and a history of concussions are identified in consensus statements as factors that influence the symptoms and neurocognitive presentation of an SRC.²⁹ The influence that these factors may have on vestibular and ocular motor function has yet to be addressed in the literature. These pre-existing conditions and factors may confound the clinical interpretation of the VOMS, and their influence on VOMS performance should be documented. The current study

examined the internal consistency of the VOMS in a large sample of healthy, nonconcussed collegiate athletes and also investigated the effects of patient sex and history of motion sickness, migraines, and concussions on baseline VOMS scores.

METHODS

Participants

A total of 394 of 417 (94.5%) eligible National Collegiate Athletic Association (NCAA) Division I collegiate student-athletes from the University of Pittsburgh were recruited and enrolled in the study during mandatory preseason physical examinations. Inclusion criteria included being a current student-athlete, being 17 to 29 years of age, being English speaking, and having the ability to provide informed consent. Exclusion criteria included a history of a neurological or vestibular disorder, previous moderate to severe traumatic brain injuries, a concussion within the past 6 months, or a current lower body injury. Complete data were available for 67% (N = 263) of the sample (166 male, 97 female). The remaining 33% of the sample were missing either complete VOMS data or medical history data. Athletes excluded from analysis because of missing data did not differ in age ($t = -1.86$, $P = .07$), sport experience ($t = -1.21$, $P = .23$), history of concussions ($\chi^2 = 0.22$, $P = .64$), presence of a learning disability ($\chi^2 = -0.51$, $P = .47$), or presence of attention deficit hyperactivity disorder (ADHD) ($\chi^2 = 0.50$, $P = .48$) compared with included participants. However, more female than male athletes were excluded because of missing data ($\chi^2 = 13.51$, $P < .001$).

Measures

Demographics and Medical History. Participants provided complete self-reported demographic and medical history at preseason physical examinations and baseline screening. Pertinent demographic data included sex, age, and sport. Pertinent medical history data included history of concussions and personal/family history of migraines, motion sickness, and psychiatric disorders. Medical information was validated with medical records to ensure accuracy.

The VOMS. The VOMS is a brief clinical screening tool that assesses vestibular and ocular motor function and symptoms and includes the following components: (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4)

*Address correspondence to Anthony P. Kontos, PhD, UPMC Center for Sports Medicine, 3200 South Water Street, Pittsburgh, PA 15203, USA (email: akontos@pitt.edu).

[†]Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania, USA.

[‡]Office for Sport Concussion Research, University of Arkansas, Fayetteville, Arkansas, USA.

The opinions, interpretations, conclusions, and recommendations of this article are those of the authors and are not necessarily endorsed by the Department of Defense (Defense Health Program funds).

One or more of the authors has declared the following potential conflict of interest or source of funding: M.W.C. is a cofounder and 10% shareholder of ImPACT Applications Inc. This research was supported in part by grants to the University of Pittsburgh from the National Institute on Deafness and Other Communication Disorders (1K01DC012332-01A1) and from the Grand Alliance of the Concussion Assessment, Research and Education Consortium, funded in part by the National Collegiate Athletic Association and the Department of Defense (United States Army Medical Research Acquisition Activity). This work was supported by the Office of the Assistant Secretary of Defense for Health Affairs through the Psychological Health and Traumatic Brain Injury Research Program (award No. W81XWH-14-2-0151).

horizontal VOR, (5) vertical VOR, (6) VMS, and (7) NPC distance. Patients rate headache, dizziness, nausea, and foggi-ness symptoms after each VOMS component on a Likert scale ranging from 0 (none) to 10 (severe). NPC distance is assessed using the average (in cm) across 3 trials. In a preliminary study, the VOMS demonstrated high overall internal consistency ($\alpha = .92$) with interitem correlations ranging from 0.44 to 0.88.³¹ For the purposes of this study, clinical cutoff scores were based on a total symptom score of ≥ 2 on any one of the VOMS items.³¹ For NPC distance, the clinical cutoff scores were based on an average NPC distance (across 3 trials) of ≥ 5 cm, per previous research.^{20,28,31,40}

Procedures

The study was approved under an expedited protocol by the university institutional review board. All participants signed written informed consent forms. Participants were administered the VOMS as part of a preseason physical examination and baseline concussion testing program that also included evaluations of baseline symptoms and neurocognitive performance. Trained research staff administered the VOMS to all participants, with all items administered in a standardized fashion (ie, metronome speed, items administered in same order). Participants also provided detailed medical history information regarding diagnosed migraines, motion sickness, and concussions as part of their evaluation. These data were also checked for accuracy against current medical records.

Statistical Analysis

Cronbach α was determined to assess internal consistency of the overall VOMS and to ascertain the contribution of each VOMS item to the overall consistency of the measure. A series of univariate nonparametric tests (χ^2 with odds ratios [ORs] and 95% CIs) were used to examine the associations among medical history risk factors and VOMS clinical cutoff scores. Clinical cutoff scores were as follows: (1) a score of ≥ 2 for any individual VOMS symptom provocation item and (2) an average NPC distance of ≥ 5 cm across 3 trials.

RESULTS

Demographic Data

The sample included 263 (166 male, 97 female) of the original 394 (67%) NCAA Division I collegiate student-athletes. The participants ranged in age from 18 to 24 years (mean \pm SD, 19.85 ± 1.35 years) and represented 9 sports (Table 1). The numbers of participants with a history of a learning disability ($n = 14$, 5.3%) and ADHD ($n = 13$, 4.9%) were consistent with the prevalence of these conditions in the general population.^{34,35} Few participants reported psychiatric diagnoses, including anxiety ($n = 3$, 1.1%) and depression ($n = 1$, 0.4%). Per exclusion criteria, no participants reported neurological impairments (eg, seizure disorder) or preexisting

TABLE 1
Sport Participation in Study Athletes (N = 263)

Sport	% (n)
Baseball	11.0 (29)
Basketball	6.1 (16)
Cross-country/track and field	12.2 (32)
Football	20.5 (54)
Soccer	14.8 (39)
Swimming/diving	18.6 (49)
Volleyball	4.6 (12)
Wrestling	5.3 (14)
Softball	6.8 (18)

vestibular conditions or diagnoses (eg, Ménière disease). Approximately a quarter (25.3%) of the sample reported a history of concussions, with 14.7% reporting 1 diagnosed concussion, 7.2% reporting 2 concussions, 3.0% reporting 3 concussions, and 0.4% ($n = 1$) reporting 5 diagnosed concussions. Diagnosed migraines were reported in 9.9% ($n = 26$) of the sample, and 3.4% ($n = 9$) of the sample reported a history of motion sickness. Only 2 participants (0.8%) reported a history of both migraines and motion sickness.

Internal Consistency

Internal consistency of the VOMS was high (Cronbach $\alpha = .97$), and 89% of athletes scored below cutoff levels (ie, score of ≥ 2 for any individual VOMS symptom, NPC distance of ≥ 5 cm) on the VOMS. All VOMS symptom provocation and NPC distance items contributed positively to the overall internal consistency of the VOMS (Table 2). The interitem correlations among VOMS symptoms were high, ranging from 0.71 to 0.96. However, the correlations between NPC distance and VOMS symptom scores were low, ranging from 0.10 to 0.14.

Risk Factors for VOMS Clinical Cutoff Scores

A majority of participants had no VOMS item scores above clinical cutoff levels (Table 3 and Figure 1). Of the remaining 11% of athletes with ≥ 1 VOMS scores above cutoff levels, 72% ($n = 21$) reported a personal history of motion sickness and/or a history in an immediate family member. Athletes with a personal history of motion sickness (OR, 7.73 [95% CI, 1.94-30.75]; $P = .009$) were more likely to have ≥ 1 VOMS scores above cutoff levels. Female athletes were significantly more likely to have ≥ 1 VOMS scores above cutoff levels (OR, 2.99 [95% CI, 1.34-6.70]; $P = .006$). Athletes with a history of concussions (OR, 1.26 [95% CI, 0.53-3.02]; $P = .370$) or migraines (OR, 1.47 [95% CI, 0.15-3.06]; $P = .460$) were no more likely to have ≥ 1 VOMS scores above cutoff levels than those with no histories (Table 4). No risk factors, including sex (OR, 1.07 [95% CI, 0.49-2.34]; $P = .52$) and history of concussions (OR, 1.40 [95% CI, 0.55-3.59]; $P = .32$), migraines (OR, 0.70 [95% CI, 0.22-2.19]; $P = .36$), and motion sickness (OR, 1.06 [95% CI, 0.11-7.79]; $P = .72$), were associated with increased odds of an abnormal NPC distance.

TABLE 2
Interitem Correlations for VOMS Assessment Domain Scores and Convergence Distance in Healthy Collegiate Athletes^a

VOMS Item	Smooth Pursuits	Horizontal Saccades	Vertical Saccades	Convergence	Horizontal VOR	Vertical VOR	VMS
Smooth pursuits	—	—	—	—	—	—	—
Horizontal saccades	0.96	—	—	—	—	—	—
Vertical saccades	0.92	0.96	—	—	—	—	—
Convergence	0.86	0.92	0.89	—	—	—	—
Horizontal VOR	0.88	0.88	0.88	0.87	—	—	—
Vertical VOR	0.92	0.89	0.86	0.88	0.89	—	—
VMS	0.71	0.74	0.71	0.77	0.74	0.80	—
NPC distance, cm	0.14	0.13	0.13	0.14	0.13	0.13	0.10

^aNPC, near point of convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Ocular Motor Screening; VOR, vestibular ocular reflex.

TABLE 3
VOMS Scores and Distribution of Normal and Abnormal VOMS Scores in Healthy Collegiate Athletes^a

VOMS Item	Score, Mean \pm SD	Normal Range, %	Above Clinical Cutoff Level (Abnormal), %
Smooth pursuits	0.35 \pm 1.39	93	7
Horizontal saccades	0.36 \pm 1.39	93	7
Vertical saccades	0.36 \pm 1.39	93	7
Horizontal VOR	0.37 \pm 1.52	93	7
Vertical VOR	0.35 \pm 1.51	94	6
VMS	0.41 \pm 1.53	92	8
NPC			
Symptoms	—	94	6
Distance, cm	2.09 \pm 2.89	89 (<5 cm)	11 (\geq 5 cm)

^aNPC, near point of convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Ocular Motor Screening; VOR, vestibular ocular reflex.

TABLE 4
Odds Ratios for Abnormal VOMS Scores by Risk Factor^a

Risk Factor	P Value	Odds Ratio (95% CI)
Female sex	.006 ^b	2.99 (1.34-6.70)
Concussion history	.370	1.26 (0.53-3.02)
Migraine history	.460	1.47 (0.15-3.06)
Motion sickness history	.009 ^b	7.73 (1.94-30.75)

^aVOMS, Vestibular/Ocular Motor Screening.

^bStatistically significant ($P < .05$).

DISCUSSION

The current study was the first to examine the internal consistency of the VOMS in a sample of healthy, nonconcussed collegiate student-athletes. This study was also the first to explore the role of risk factors on vestibular and ocular motor symptoms and function in this population. The VOMS demonstrated good internal consistency and yielded a relatively low false-positive rate of 11%. With regard to risk factors, among student-athletes with VOMS scores above clinical cutoff levels, 72% had a history of motion sickness. Additionally, female athletes were at a greater risk for VOMS scores above clinical cutoff levels. However, other known risk factors for concussion-related outcomes, including a history of

concussions and migraines, were not associated with VOMS scores above clinical cutoff levels.

The findings provide additional statistical support for the internal consistency of the VOMS tool. The internal consistency for the VOMS total score among healthy collegiate student-athletes was high (Cronbach $\alpha = .97$) and similar to the internal consistency of the VOMS among healthy and concussed youth athletes previously reported (Cronbach $\alpha = .94$).³¹ Internal consistency of the VOMS is similar to other self-reported symptom-based measures used in concussion assessments, such as the Post-Concussion Symptom Scale (Cronbach $\alpha = .88-.94$)²⁷ and Dizziness Handicap Inventory (Cronbach $\alpha = .89$).²² Few other tools developed to assess vestibular or ocular impairments after a concussion have been adequately researched. A frequently used screening tool that focuses on timed saccadic eye movements, the King-Devick test, is reported to have adequate, although lower, internal consistency (Cronbach $\alpha = .72-.76$)²⁵ than reported in the current study for the VOMS. Further, internal consistency of the VOMS is higher than that of another commonly used screening tool to assess vestibular functioning, the Functional Gait Assessment (Cronbach $\alpha = .79$).⁴²

In the current sample, 89% of healthy collegiate athletes scored below published clinical cutoff levels (ie, symptom scores <2 on all VOMS items) previously established in a younger sample of healthy athletes with similar mean scores on the VOMS (Figure 1). Among the 11% ($n = 28$) of healthy

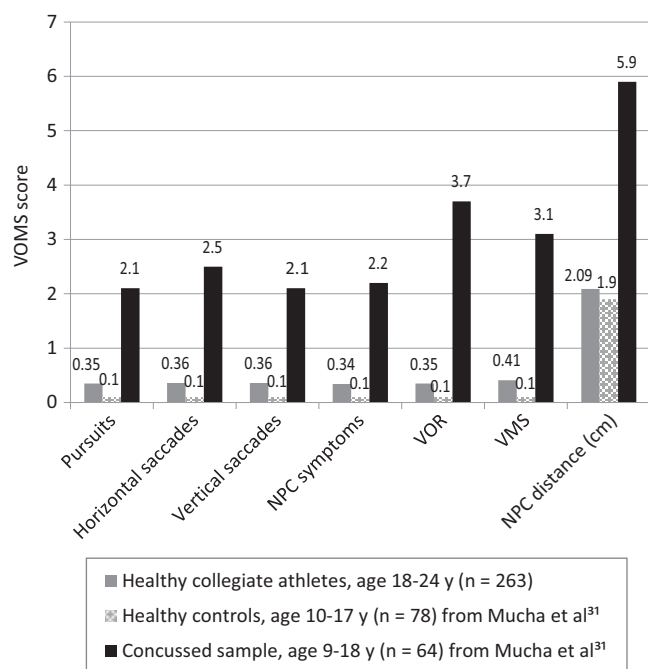


Figure 1. Mean Vestibular/Ocular Motor Screening (VOMS) scores for healthy collegiate athletes compared to previously published normative data (Mucha et al³¹) for concussed athletes. NPC, near point of convergence; VMS, visual motion sensitivity; VOR, vestibular ocular reflex.

athletes with false-positive VOMS scores (ie, symptom scores <2 on any VOMS item), 60% (n = 21) also had a history of motion sickness. Consequently, only 3% (n = 7) of the sample had a true false-positive rate that was not associated with motion sickness. This rate is less than those reported for other concussion-related assessment tools.^{4,21,37} There is some evidence to suggest that using baseline data rather than normative data can reduce false-positive rates for neurocognitive testing.^{38,41} Not surprisingly, motion sickness was also associated with a 7.73 times higher risk for at least 1 VOMS item above the clinical cutoff level. Female athletes had a 2.99 times higher risk for at least 1 VOMS item above the clinical cutoff level compared with male athletes. This finding may reflect research that has supported a stronger proclivity for motion sickness among female patients.^{13,23} A history of migraines was not associated with VOMS scores or NPC distance. This finding is surprising, given that motion sickness is reported in 50% of patients with migraines²⁴ and the co-occurrence of migraines and dizziness or vertigo is often referred to as vestibular migraine in clinical settings.¹⁸ Surprisingly, only 2 participants (0.8%) in our sample reported both motion sickness and migraines. A vestibular migraine is more challenging to diagnose in a younger population,²⁶ and other migraine subtypes may be more prominent or disproportionately represented in our sample. A history of concussions was also not associated with VOMS scores, suggesting that vestibular and oculomotor deficits that may be present in the acute and subacute period after an SRC may not result in residual dysfunction or symptoms in this domain.^{7,15}

Clinical Implications

The findings in the current study provide important clinical considerations for the sports medicine professional responsible for conducting a comprehensive SRC evaluation. The VOMS was intended to be used as a screening tool after concussions in the absence of baseline data and has high sensitivity for the diagnosis of concussions.³¹ The current findings indicated that only a small percentage of athletes, predominantly female, have abnormal baseline VOMS scores that are likely related to preexisting motion sickness. Similarly, an abnormal NPC distance occurred in only 11% of our sample, which is consistent with childhood and college population estimates of 6% to 14%.^{9,36} Together, these findings suggest that there is a low false-positive rate for the VOMS at baseline among collegiate student-athletes. Researchers have previously reported on false-positive rates or abnormal performance across other tools used in concussion management among healthy athletes. For example, athletes diagnosed with learning disabilities perform below average on baseline neurocognitive testing,¹⁶ and athletes with a history of ankle injuries perform worse on the Balance Error Scoring System at baseline.¹⁴ The findings from the current study continue to reinforce the need for multiple tools and a comprehensive assessment approach to SRCs. Moreover, understanding preexisting and constitutional risk factors that may influence both baseline and postinjury performance on tests is needed to discern the effects of injuries from preexisting deficits. In short, evaluating and managing SRCs for athletes with complex medical and developmental histories can be challenging in the absence of a multifaceted approach to assessing this injury.

Strengths and Limitations

The current study was the first to examine the role of risk factors on vestibular and ocular motor symptoms and function in a large sample of collegiate student-athletes. Although medical history data were collected via self-reports, they were also checked for accuracy against current medical records. However, not all data (eg, motion sickness) were included in the medical records, so the accuracy of these data may be influenced by self-report bias. Similarly, we assumed that symptoms reported after each VOMS item were reported honestly and accurately. Because of the availability of athletes, only single evaluation time points were available, and therefore, test-retest reliability was not available. Another limitation was the use of forced dichotomous categorization for the presence or absence of motion sickness susceptibility, despite evidence that motion sickness susceptibility is a construct that occurs on a continuum and changes across time and development stages.³³ Our findings are limited to collegiate student-athletes and may not be generalizable to other age groups or levels of sport participation.

Future Directions

Examining the relationship between abnormal baseline VOMS and SRC outcomes may help researchers gain insight into the potential link between risk factors and poor

outcomes after an SRC. To date, researchers have yet to examine motion sickness as a risk factor for delayed recovery and specific impairments, despite evidence that motion sickness is linked to vestibulopathy.³² Clinical researchers have recently suggested that a concussion may magnify preexisting dysfunction, resulting in specific clinical trajectories and further supporting the importance of research that connects risk factors such as motion sickness with vestibular clinical trajectories.⁸ The current findings indicated that female athletes were more likely to have baseline VOMS scores above clinical cutoff levels. Several studies have suggested that female patients are at risk for worse outcomes after an SRC,^{5,11,17} although the interaction between vestibular dysfunction and sex differences after injuries has not been considered as an explanation for this finding. The risk factors for vestibular symptoms and dysfunction that were examined in this study were not exhaustive, and other factors need to be explored. For example, because of the potential influence of stress³⁹ and hormones^{1,19} on vestibular functioning, the menstrual cycle may be implicated in symptom reporting on the VOMS. According to the results from the current study and the Mucha et al³¹ study, age does not seem to affect VOMS scores in healthy athletes, provided similar means and SDs across symptoms scores and measurement of NPC distance. However, further examination of age-related differences is warranted, provided the known influence of age on motion sickness susceptibility.³³ Moving forward, researchers should examine additional risk factors that could influence measurement of the NPC distance and other oculomotor dysfunction at baseline. Strabismus, reading disorder, dyslexia, and ADHD have all been linked to ocular motor dysfunction.^{3,6,30} A future evaluation of these factors in relation to VOMS performance may identify additional sources of variability in oculomotor dysfunction. Establishing test-retest reliability of the VOMS is important, as it may lead to the establishment of reliable change indexes for vestibular and oculomotor outcomes after a concussion such that baseline scores would not be necessary. Finally, as is the case with all measures used in the sport concussion arena, it may be useful to identify or develop appropriate effort and validity indicators for the VOMS.

CONCLUSION

The findings indicate that the VOMS possesses internal consistency and an acceptable false-positive rate among healthy NCAA Division I student-athletes. Female sex and a history of motion sickness were risk factors for VOMS scores above clinical cutoff levels among healthy collegiate student-athletes. Our findings highlight the importance of a comprehensive baseline evaluation that includes an assessment of premorbid vestibular and oculomotor functioning and related medical history (eg, motion sickness susceptibility) in light of the risk factors identified in this study. Moving forward, researchers should examine prospectively the role of the risk factors from the current study on subsequent vestibular and oculomotor symptoms and dysfunction after concussions in collegiate as well as pediatric and adolescent populations.

REFERENCES

1. Black FO. Maternal susceptibility to nausea and vomiting of pregnancy: is the vestibular system involved? *Am J Obstet Gynecol*. 2002;186(5):S204-S209.
2. Bolding MI, Ljstad U, Mygland A, Monstad P. Vestibular sensitivity in vestibular migraine: VEMPs and motion sickness susceptibility. *Cephalalgia*. 2011;31(11):1211-1219.
3. Borsting E, Rouse M, Chu R. Measuring ADHD behaviors in children with symptomatic accommodative dysfunction or convergence insufficiency: a preliminary study. *Optometry*. 2005;76(10):588-592.
4. Broglio SP, Ferrara MS, Macciocchi SN, Baumgartner TA, Elliott R. Test-retest reliability of computerized concussion assessment programs. *J Athl Train*. 2007;42(4):509.
5. Broshek DK, Kaushik T, Freeman JR, Erlanger D, Webbe F, Barth JT. Sex differences in outcome following sports-related concussion. *J Neurosurg*. 2005;102(5):856-863.
6. Bucci MP, Malithe D, Ajrezo L, Bui-Quoc E, Garard C-L. The influence of oculomotor tasks on postural control in dyslexic children. *Front Hum Neurosci*. 2014;8:981.
7. Buckley TA. Acute and lingering impairments in post-concussion postural control. In: Slobounov SM, Sebastianelli WJ, eds. *Concussions in Athletics: From Brain to Behavior*. New York: Springer; 2014:139-165.
8. Collins M, Kontos A, Reynolds E, Murawski C, Fu F. A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(2):235-246.
9. Convergence Insufficiency Treatment Trial (CITT) Study Group. The convergence insufficiency treatment trial: design, methods, and baseline data. *Ophthalmic Epidemiol*. 2008;15(1):24-36.
10. Corwin DJ, Wiebe DJ, Zonfrillo MR, et al. Vestibular deficits following youth concussion. *J Pediatr*. 2015;166(5):1221-1225.
11. Covassin T, Elbin R, Bleecker A, Lipchik A, Kontos AP. Are there differences in neurocognitive function and symptoms between male and female soccer players after concussions? *Am J Sports Med*. 2013;41(12):2890-2895.
12. Cullen KE. The vestibular system: multimodal integration and encoding of self-motion for motor control. *Trends Neurosci*. 2012;35(3):185-196.
13. Dobie T, McBride D, Dobie T Jr, May J. The effects of age and sex on susceptibility to motion sickness. *Aviat Space Environ Med*. 2001;72(1):13-20.
14. Docherty CL, McLeod TCV, Shultz SJ. Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clin J Sport Med*. 2006;16(3):203-208.
15. Elbin R, Covassin T, Henry L, Whalen DJ, Wedge J, Kontos AP. Sport-related concussion: "how many is too many?" *Transl Stroke Res*. 2013;4(4):425-431.
16. Elbin R, Kontos AP, Kegel N, Johnson E, Burkhart S, Schatz P. Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Arch Clin Neuropsychol*. 2013;28(5):476-484.
17. Frommer LJ, Gurka KK, Cross KM, Ingersoll CD, Comstock RD, Saliba SA. Sex differences in concussion symptoms of high school athletes. *J Athl Train*. 2011;46(1):76.
18. Furman JM, Marcus DA. Migraine and motion sensitivity. *Continuum (Minneapolis)*. 2012;18(5 Neuro-otology):1102-1117.
19. Hammar ML, Lindgren R, Berg GE, Mailler CG, Niklasson MK. Effects of hormonal replacement therapy on the postural balance among postmenopausal women. *Obstet Gynecol*. 1996;88(6):955-960.
20. Hayes GJ, Cohen BE, Rouse MW, De Land PN. Normative values for the nearpoint of convergence of elementary schoolchildren. *Optom Vis Sci*. 1998;75(7):506-512.
21. Hinton-Bayre AD, Geffen GM, Geffen LB, McFarland KA, Frijs P. Concussion in contact sports: reliable change indices of impairment and recovery. *J Clin Exp Neuropsychol*. 1999;21(1):70-86.
22. Jacobson GP, Newman CW. The development of the dizziness handicap inventory. *Arch Otolaryngol Head Neck Surg*. 1990;116(4):424-427.

23. Jokerst MD, Gatto M, Fazio R, Gianaros PJ, Stern RM, Koch KL. Effects of gender of subjects and experimenter on susceptibility to motion sickness. *Aviat Space Environ Med.* 1999;70(10):962-965.
24. Kayan A, Hood JD. Neuro-otological manifestations of migraine. *Brain.* 1984;107(4):1123-1142.
25. King D, Clark T, Gissane C. Use of a rapid visual screening tool for the assessment of concussion in amateur rugby league: a pilot study. *J Neurol Sci.* 2012;320(1-2):16-21.
26. Langhagen T, Lehrer N, Borggraefe I, Heinen F, Jahn K. Vestibular migraine in children and adolescents: clinical findings and laboratory tests. *Front Neurol.* 2014;5:292.
27. Lovell MR, Iverson GL, Collins MW, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Appl Neuropsychol.* 2006;13(3):166-174.
28. Maples WC, Hoenes R. Near point of convergence norms measured in elementary school children. *Optom Vis Sci.* 2007;84(3):224-228.
29. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med.* 2013;47(5):250-258.
30. Mostofsky SH, Lasker A, Cutting L, Denckla M, Zee D. Oculomotor abnormalities in attention deficit hyperactivity disorder: a preliminary study. *Neurology.* 2001;57(3):423-430.
31. 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.
32. Murdin L, Chamberlain F, Cheema S, et al. Motion sickness in migraine and vestibular disorders. *J Neurol Neurosurg Psychiatry.* 2015;86(5):585-587.
33. Park AH-Y. Age differences in self-reported susceptibility to motion sickness. *Percept Mot Skills.* 1998;87(3 Pt 2):1202.
34. Pastor PN, Reuben CA. Diagnosed attention deficit hyperactivity disorder and learning disability: United States, 2004-2006. *Vital Health Stat 10.* 2008;(237):1-14.
35. Polanczyk G, de Lima MS, Horta BL, Biederman J, Rohde LA. The worldwide prevalence of ADHD: a systematic review and meta-regression analysis. *Am J Psychiatry.* 2007;164(6):942-948.
36. Porcar E, Martinez-Palomera A. Prevalence of general binocular dysfunctions in a population of university students. *Optom Vis Sci.* 1997;74(2):111-113.
37. Resch J, Driscoll A, McCaffrey N, et al. ImPact test-retest reliability: reliably unreliable? *J Athl Train.* 2012;48(4):506-511.
38. Roebuck-Spencer TM, Vincent AS, Schlegel RE, Gilliland K. Evidence for added value of baseline testing in computer-based cognitive assessment. *J Athl Train.* 2013;48(4):499.
39. Saman Y, Bamiou D, Gleeson M, Dutia MB. Interactions between stress and vestibular compensation: a review. *Front Neurol.* 2012;3:116.
40. Scheiman M, Gallaway M, Frantz KA, et al. Nearpoint of convergence: test procedure, target selection, and normative data. *Optom Vis Sci.* 2003;80(3):214-225.
41. Schmidt JD, Register-Mihalik JK, Mihalik JP, Kerr ZY, Guskiewicz KM. Identifying impairments after concussion: normative data versus individualized baselines. *Med Sci Sports Exerc.* 2012;44(9):1621-1628.
42. Wrisley DM, Marchetti GF, Kuharsky DK, Whitney SL. Reliability, internal consistency, and validity of data obtained with the functional gait assessment. *Phys Ther.* 2004;84(10):906-918.
43. Zur O, Schoen G, Dickstein R, et al. Anxiety among individuals with visual vertigo and vestibulopathy. *Disabil Rehabil.* 2015;37(23):2197-2202.

Copyright of American Journal of Sports Medicine is the property of Sage Publications Inc. and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.