

Preseason Vestibular Ocular Motor Screening in Children and Adolescents

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Abstract

Objectives: The primary purpose of this study was to examine vestibular/ocular motor screening (VOMS) test performance in a sample of healthy youth ice hockey players. A particular focus was to investigate the potential effects of age and pre-existing health conditions, including concussion history, attention-deficit/hyperactivity disorder (ADHD), learning disability (LD), headaches/migraines, and depression/anxiety on preseason baseline VOMS performance, including the near point of convergence (NPC) distance. **Design:** Cross-sectional cohort. **Setting:** Outpatient physiotherapy clinic. **Participants:** Three hundred eighty-seven male youth hockey players, with an average age of 11.9 years (SD = 2.2, range = 8–17), completed the VOMS and responded to self- or parent-reported demographic and medical history questionnaires during preseason baseline assessments. **Independent Variables Assessed:** Age, sex, and mental and physical health history including ADHD, headaches, depression, anxiety, migraine, and LD. **Outcome Measure:** Vestibular/ocular motor screening. **Results:** The large majority of boys scored within normal limits on the VOMS, ie, they reported no symptom provocation of more than 2 points on any VOMS subset (89%) and had a normal NPC distance, ie, <5 cm (78%). The individual VOMS subtests had low abnormality rates, and demographic and pre-existing health conditions, such as age, headache or migraine history, previous neurodevelopmental conditions, or mental health problems, were not associated with clinically meaningful symptom provocation during the VOMS. **Conclusions:** There was a low rate of abnormal findings for the individual VOMS subtests, with the exception of NPC distance, among male youth hockey players during preseason assessment.

Key Words: concussion, clinical assessments, VOMS, children

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INTRODUCTION

The vestibular system includes 2 main parts—the vestibulo-ocular system and the vestibulospinal system—and it is essential for the sense of orientation in space, self-motion, and gaze stabilization.¹ Thus, vestibular system dysfunction often manifests as dizziness, gaze instability, and deficits in visual motion sensitivity (VMS).¹ The vestibulospinal system, in particular, is important for postural control, and impairments result in postural instability.²

The vestibular system is vulnerable to injury from head trauma and concussion. A diverse number of self-reported visual-ocular problems have been documented after a concussion such as diplopia, blurred vision, impaired eye movements, difficulty reading, dizziness, ocular pain, and poor visual-based concentration.^{3–7} Some children and adolescents who sustain concussions experience vision problems, such as accommodative disorders, convergence insufficiency, and saccadic dysfunction.⁶ Further, visual–vestibular impairments were common in children and adolescents who presented to a specialty clinic after a concussion, with 74% of patients presenting with symptom provocation after oculomotor examination and 62% having abnormal convergence.⁸ Moreover, youth who presented with visual–vestibular impairments took longer to return to school and to sports compared with those who did not have these problems—and they were more likely to remain symptomatic for more than 4 weeks.^{8,9}

Therefore, vestibular and ocular motor assessment methods may provide important data for the early identification and ongoing clinical management of pediatric concussion. The

vestibular/ocular motor screening (VOMS) assessment was developed to identify vestibular and/or ocular motor impairments after a concussion through patient-reported symptom provocation.¹⁰ The VOMS consists of 7 tasks: smooth pursuit, saccades (vertical and horizontal), near point of convergence (NPC), vestibular ocular reflex (VOR; vertical and horizontal), and VMS. After each subtest, the severity of 4 symptoms (headache, dizziness, nausea, and foggiess) is reported on a 10-point scale, with an individual symptom severity change ≥ 2 points representing clinically meaningful symptom provocation.^{10,11} Recent work has illustrated the added value of assessing vestibular-oculomotor symptoms during clinical evaluations for sport-related concussion.¹² In addition, the NPC distance is an important screening test for convergence insufficiency, which is common after concussion.^{6,13}

Previous research suggests that the VOMS has high internal consistency reliability (ie, high correlations among VOMS subtests) and low rates of positive findings among uninjured Division 1 collegiate athletes.¹¹ The VOMS has relatively low rates of positive findings in uninjured adolescents^{14,15} too, including in those who are tested on the sideline after exercise.¹⁶ In addition, some demographic and health history factors are related to VOMS performance. Among collegiate athletes, female sex and a history of motion sickness are associated with higher baseline, preseason VOMS scores.¹¹ By contrast, other factors such as previous concussions or history of migraines are not associated with VOMS scores.¹¹ The VOMS is sensitive to the effects of concussion in high school athletes,^{17,18} and abnormality on the VOMS is associated with slower recovery in youth athletes.^{19,20} After concussion, the VOR subtest seems to elicit the greatest symptom provocation (61% of patients), and concussed athletes have a greater mean NPC distance relative to uninjured athletes ($d = 0.68$, medium effect size).¹⁰ Preinjury motion sickness is also associated with greater symptom provocation in the subacute period after concussion in youth athletes.¹⁸

Although previous studies support the clinical value of the VOMS for collegiate athletes, limited data are available regarding how pediatric athletes, both healthy and concussed, perform on the VOMS. Furthermore, pre-existing conditions may confound clinical interpretation of VOMS performance. For example, both attention-deficit/hyperactivity disorder (ADHD) and learning disability (LD) are associated with differences in oculomotor function.^{21–23} Thus, the objectives of the current study were to (1) report VOMS data from a sample of healthy, uninjured male youth hockey players, (2) examine the internal consistency (the degree of correlation among subsets) of the VOMS, and (3) examine the associations between VOMS scores and demographic/health history variables such as age, ADHD, LD, headache or migraine history, and depression or anxiety.

METHODS

Study participants were players from a regional minor youth hockey association in British Columbia, Canada, who completed a baseline VOMS evaluation before the 2015 to 2016 season. Owing to the small number of girls in the league, only data from the boys were analyzed. The full sample included 387 boys with ages ranging from 8 to 17, none of which were excluded.

After each of 7 brief subtests, patients verbally self-report the severity of 4 symptoms: headache, dizziness, nausea, and foggiess, in comparison with their immediate preassessment state using a Likert scale ranging from 0 (none) to 10 (severe). In this way, clinicians can determine whether each VOMS subtest provokes symptoms. To measure NPC, participants slowly move an accommodative target (in our study, the letter X marked on an oversized tongue depressor, consistent with previous work¹⁰) toward their nose and self-reported the point at which they experienced diplopia (ie, double vision). The NPC distance was measured as the distance from the tip of the nose to the target when the patient reported diplopia and averaged across 3 separate trials.¹⁰ Normal NPC values were defined as an average NPC distance of less than 5 cm across the 3 trials.^{10,11} For the purposes of this study, a clinically meaningful change in symptoms, ie, “the clinical cutoff,” was defined as either (1) a change in symptom severity of ≥ 2 points on any of the 4 individual symptoms (ie, headache, dizziness, nausea, or foggiess) during any of the VOMS subtests or (2) an average NPC distance of ≥ 5 cm, as per previous studies.^{10,11} For example, if a participant reported a 2-point increase in headache severity on smooth pursuit, they would be considered “provoked.” Two total scores were calculated for this study: the original total score,¹⁰ which is based on summing the symptom provocation scores for the 7 VOMS tasks (ie, 7 tasks with 4 symptom ratings each = 28 ratings), and a modified total score,¹² which is calculated the same way except that the near-point convergence symptom provocation score is not included (ie, 6 tasks with 4 symptom ratings each = 24 ratings). The modified total score was analyzed to allow for comparison with other studies.¹²

The minor hockey association’s concussion protocol mandates that all registered players undergo preseason testing, which included the VOMS. Before the evaluation, parents provided written consent and players provided assent. Evaluations were completed in private rooms by certified athletic therapists, physical therapists, or trained graduate students. Test administrators received standardized training in testing procedures before data collection. All health history information included in this study is retrospective and based on parent/self-report. The study was approved by the University of British Columbia’s Clinical Research Ethics Board.

Vestibular/ocular motor screening scores and the percentage of youth scoring above cutoffs were analyzed overall and stratified by several demographic and pre-existing health condition variables including age [child (age 8–12 years) and adolescent (age 13–17 years)], history of multiple previous concussions (0, 1, or >1), history of headaches or migraines (yes/no), history of depression or anxiety (yes/no), and diagnosis of ADHD or LD (yes/no). Owing to non-normally distributed data and unequal cell sizes, nonparametric analyses were used. More specifically, we examined whether any demographic and/or pre-existing health conditions were associated with greater average symptom provocation using Mann–Whitney *U* tests or were associated with greater likelihood of scoring above cutoffs on the VOMS using χ^2 tests. Cronbach’s alpha (α) was computed to examine the internal consistency of VOMS symptom provocation ratings (ie, increases in the 4 symptoms after each provocation task). Internal consistency coefficients (ie, correlations among VOMS subtests) were calculated for each subtest of the VOMS as well as the total score and the modified total score

TABLE 1. Descriptive Data for VOMS Performance

Variables	N	Mean	SD	IQR	Range	Cronbach's Alpha
VOMS subtest						
Smooth pursuit	387	0.10	0.75	0-0	0-12	0.81
Horizontal saccades	387	0.15	0.78	0-0	0-10	0.59
Vertical saccades	387	0.14	0.75	0-0	0-12	0.70
Near-point convergence	371	0.13	0.75	0-0	0-11	0.72
Horizontal VOR	387	0.25	0.91	0-0	0-10	0.62
Vertical VOR	386	0.21	0.81	0-0	0-8	0.42
Visual motion sensitivity	386	0.23	1.20	0-0	0-18	0.81
Total VOMS score	370	1.23	4.78	0-0	0-70	0.92
Modified VOMS score	386	1.07	4.10	0-0	0-59	0.90
Near-point convergence distance (cm)	382	3.04	3.33	2.33-4.33	0.00-23.00	NA

The modified VOMS score is the total of the 6 provocation tasks omitting near-point convergence.^{1,2} Internal consistency estimates are based on change/provocation scores. IQR, interquartile range; NA, not applicable; VOMS, vestibular/ocular motor screening; VOR, vestibular ocular reflex.

(ie, the total of the 6 provocation tasks omitting near-point convergence¹²). All statistical analyses were performed using SPSS Version 23, except for relative risks and their 95% confidence intervals (CIs), which were calculated using an online 2-way contingency table calculator (<http://statpages.info/ctab2x2.html>).

RESULTS

The mean age of the 387 boys was 11.9 years (SD = 2.2, range 8-17). The majority of participants (60.5%; $n = 234$) were below the age of 13 and were considered child athletes, with the remaining 39.5% ($n = 153$) categorized as adolescent athletes (ages 13-17 years). The rate of previous concussions in the total sample was 20.4% ($n = 79$, range 1-4), with the majority of these youth ($n = 53$) reporting 1 previous concussion. Health history problems were uncommon overall. Only 4.4% ($n = 17$) of youth reported a previous diagnosis of a headache disorder, 3.4% ($n = 13$) reported a previous diagnosis of migraine, 7.5% ($n = 29$) reported a previous diagnosis of ADHD, 1.6% ($n = 6$) reported a previous diagnosis of LD, and only 2.6% ($n = 10$) reported a previous diagnosis of depression, anxiety, or other psychiatric disorders.

Descriptive data on VOMS performance are presented in Table 1. The rates at which symptoms were provoked during each VOMS subtest are presented in Table 2. Among healthy, uninjured boys, specificity was high for the individual VOMS subtests; in that, it was uncommon for these tasks to provoke symptoms (Table 2). That is, the vast majority of healthy uninjured boys “passed” or were “negative” on the VOMS subtests. However, 1 in 10 youth (10.6%) were “abnormal” and scored outside of the clinical cutoff on at least one of the VOMS symptom provocation subtests. In addition, 1 in 5 (22.3%) were “abnormal” on NPC distance (ie, average distance ≥ 5 cm). Overall, 29.3% of boys scored above clinical cutoffs on at least one symptom provocation test or NPC distance. Put another way, more than one-quarter of healthy boys would be classified as abnormal on some part of the VOMS.

As an exploratory analysis, we also examined abnormality rates on symptom provocation subtests using cutoff scores of ≥ 1 and ≥ 3 (also presented in Table 2). For the lower cutoff, the rate of symptom provocation across individual subtests ranged from 4.6% to 11.6%, and 22.7% had provocation on

at least one of the subtests when considering all subtests simultaneously. For the higher cutoff, symptom provocation was rare for the individual subtests, and only 4.1% of participants had one or more positive symptom provocation subtests when all subtests were considered simultaneously. Adjusting the NPC distance cutoff to >6 cm resulted in a reduction in the NPC abnormality rate from 22.3% to 11.8%, and adjusting to >7 cm resulted in a reduction of the abnormality rate to 7.6%. Considering different cutoffs of ≥ 3 for symptom provocation and >6 cm for NPC distance in combination, 15.5% scored above clinical cutoffs on any part of the VOMS. Considering different cutoffs of ≥ 3 for symptom provocation and >7 cm for NPC distance in combination, about 1 in 10 healthy youth (11.6%) scored above clinical cutoffs on any part of the VOMS.

Internal consistency of the VOMS symptom provocation total scores was high (Cronbach $\alpha = 0.92$; 28 items). The modified VOMS total score also had high internal consistency reliability ($\alpha = 0.90$; 24 items). For individual subtests (comprised 4 items each), internal consistency ranged from medium to high. Horizontal saccades ($\alpha = 0.59$) and both horizontal ($\alpha = 0.62$) and vertical ($\alpha = 0.42$) vestibular-ocular reflex had much lower internal consistency reliability than the other subtests (Table 1).

With a few exceptions, demographic and health history factors were not associated with increased risk of scoring above the VOMS symptom provocation subtests or the NPC distance cutoffs (χ^2 tests). That is, children between the ages of 8 to 12 years and adolescents between the ages of 13 to 17 years did not differ in the proportion of boys scoring above clinical cutoffs on NPC distance or any VOMS provocation subtest. Similarly, boys with and without ADHD or LD, headaches or migraines, and depression or anxiety did not differ in the proportion scoring above clinical cutoffs on NPC distance or any VOMS provocation subtest. However, youth with at least 1 previous concussion (3.8%) were more likely than youth without a concussion history (0.3%) to score above the clinical cutoff on smooth pursuits [χ^2 ($N = 387$) = 7.41, $P = 0.006$, RR, 3.78; 95% CI, 1.08-5.04]—although this difference was very small from a clinical perspective.

More boys with abnormal NPC distance (ie, 7.1%) than boys with normal NPC distance (ie, 2%) scored above the cutoff on

TABLE 2. Percentage of Healthy Youth Reporting Symptom Provocation on Each VOMS Subtest (Cutoff Score ≥ 2 and ≥ 3)

VOMS Subtest	% With Symptom Provoked				
	Headache	Dizziness	Nausea	Fogginess	Any Symptom
Smooth pursuit	[1.8] 0.5 (0.5)	[2.6] 0.8 (0.5)	[0.8] 0.5 (0)	[1.6] 0.3 (0)	[4.6] 1.0 (0.8)
Horizontal saccades	[2.1] 0.5 (0)	[4.1] 2.3 (1.0)	[0.5] 0.3 (0)	[2.1] 0.8 (0.3)	[6.7] 3.1 (1.0)
Vertical saccades	[2.3] 0.3 (0.3)	[4.4] 1.8 (0.3)	[0.8] 0.3 (0)	[2.3] 0.8 (0.8)	[7.8] 2.3 (0.8)
Near-point convergence	[3.1] 0.5 (0)	[1.8] 0.8 (0.3)	[0.5] 0.5 (0)	[2.6] 1.0 (0.8)	[5.9] 1.8 (0.8)
Horizontal VOR	[2.8] 1.3 (0.3)	[9.3] 3.9 (1.3)	[1.8] 0.3 (0)	[2.3] 0.8 (0)	[11.6] 4.7 (1.6)
Vertical VOR	[3.4] 1.0 (0.3)	[7.2] 2.6 (1.3)	[1.8] 0.5 (0)	[2.1] 0.3 (0)	[10.9] 3.6 (1.6)
Visual motion sensitivity	[3.1] 1.3 (0.3)	[7.8] 2.3 (1.0)	[2.1] 0.3 (0)	[2.3] 1.0 (0.3)	[9.3] 3.1 (1.0)
Any subtest	[8.0] 3.1 (1.0)	[17.1] 7.5 (2.8)	[4.4] 1.3 (0)	[7.8] 2.8 (1.3)	[22.7] 10.6 (4.1)
Any subtest (modified VOMS)	[7.5] 2.6 (1.0)	[17.1] 7.5 (2.8)	[4.1] 1.0 (0)	[6.7] 2.1 (0.8)	[22.5] 10.1 (3.6)

*The modified VOMS score is the total of the 6 provocation tasks omitting near-point convergence.¹² The percentages of boys reporting symptom provocation based on a cutoff score ≥ 1 for the first number [presented in brackets], ≥ 2 is the second number, and ≥ 3 (presented in the parentheses).
VOMS, vestibular/oculomotor screening; VOR, vestibular ocular reflex.*

horizontal saccades [χ^2 ($N = 382$) = 5.51, $P = 0.019$, RR, 2.34; 95% CI, 1.01-3.78]—once again, this difference is of minimal clinical significance. These groups differed significantly on the VOMS total score (Mann–Whitney $U = 9854.0$, $P < 0.01$), with the normal NPC group reporting less symptom provocation. However, the magnitude of this difference was negligible ($d = 0.08$). These 2 groups also differed significantly on the modified VOMS total score (Mann–Whitney $U = 10336.0$, $P < 0.01$), again with the normal NPC group reporting less symptom provocation. However, as with the VOMS total score, the magnitude of this difference was negligible ($d = 0.10$).

DISCUSSION

This study examined VOMS performance in a large sample of boys before their hockey season. Applying suggested cutoffs from the VOMS developers,¹⁰ there were low abnormality rates for symptom provocation on each of the 6 individual VOMS subtests (ie, 1%-5%). The symptom most likely to be provoked was dizziness (7.5%), and the symptom least likely to be provoked was nausea (1.3%). Low abnormality rates for symptom provocation across the individual VOMS subtests have been reported in previous studies with college students^{10,11} and with youth athletes.^{14,15} When all subtests relating to symptom provocation were considered simultaneously, the overall rate of abnormality for the entire test in the present sample was 10.6%. This rate is the same as the proportion of Division I collegiate athletes who had at least 1 abnormality (11%) on the VOMS.¹¹ Most previous published studies, however, have only reported abnormality rates for each subtest individually, not all subtests simultaneously (ie, the rate of having one or more positive subtests across the entire VOMS). Clinicians, of course, interpret the entire test—so future researchers should report the rate of abnormality across the entire VOMS, not just the individual subtests. In the present sample, demographic and pre-existing health conditions, such as age, headache or migraine history, and previous neurodevelopmental or mental health problems, were not associated with clinically meaningful symptom provocation during the VOMS. These results are consistent with a past study with collegiate athletes.¹¹

In this study, 22.3% of these boys had “abnormal” near-point convergence, defined as greater than or equal to 5 cm. This rate is considerably higher than the rate reported for Division 1 collegiate athletes (ie, 11%) and the rate reported for a large sample of children and adolescents between the ages of 8 and 14 years (ie, 10.6%).¹⁵ However, Yorke et al¹⁴ reported that 25% of their sample of 105 high school students demonstrated near-point convergence ≥ 5 cm. More research is needed to better understand near-point convergence in student athletes, as measured by the VOMS, and whether examiner-related measurement error might contribute to the variability in findings across studies.

The internal consistency of the VOMS found among our group of participants (Cronbach $\alpha = 0.92$) is similar to that reported by Mucha et al¹⁰ ($\alpha = 0.91$), Kontos et al¹¹ ($\alpha = 0.97$), and Moran et al¹⁵ ($\alpha = 0.97$). These values are comparable or higher than other concussion management measures including questionnaires, such as the Post-Concussion Symptom Scale ($\alpha = 0.88$ -0.94²⁴) and Dizziness Handicap Inventory ($\alpha = 0.89$ ²⁵), and performance-based tasks such as the King-Devick test ($\alpha = 0.72$ -0.76²⁶).

This study has several limitations. First, we had only a small number of participants reporting pre-existing health conditions of interest (ie, previous concussion, ADHD or LD, and anxiety or depression). Thus, we may have been underpowered to detect small effects. Second, given the nature of our sample, this study only included boys. Previous research on the VOMS reported differential associations between boys and girls¹¹; thus, further investigation into sex-related differences among youth is warranted. Third, youth and their parents reported health diagnoses during baseline testing, and we were not able to confirm previous health conditions with a formal diagnosis or medical record review. Notably, self- or parent-reported health history information is often the only information source available for baseline and rapid screening assessments in applied clinical situations. Finally, our rate of abnormal NPC scores might have been artificially inflated because we had several examiners completing the VOMS and measuring NPC can be difficult to do swiftly and accurately when engaged in baseline testing of large numbers of athletes.

Our findings suggest negligible impact of pre-existing conditions on VOMS scores in younger male athletes, which is

consistent with previous studies. The consistency of both VOMS subtest and NPC distance measures across different health demographics (history of previous concussion, history of ADHD/LD, history of headaches/migraines, and history of depression/anxiety/other psychiatric disorders) supports the use of the VOMS as a component of a multifaceted evaluation and management approach for concussion in athletes. This may be a notable strength of the VOMS because other concussion assessment tools might be more affected by, for example, ADHD/LD diagnosis.^{21,27–34} In addition, the lack of significant differences between child and adolescent athletes on the VOMS subtests suggests that separate clinical cutoffs might not be necessary in these age ranges. By contrast, young athletes (12 years of age and younger) demonstrate less proficiency on various SCAT2 components than their older counterparts.^{35,36} Therefore, use of the VOMS may be appropriate in the context of concussion management across a broader age spectrum compared with other concussion tests. More research with children and adolescents is needed, however, to determine more definitively whether there are or are not developmental differences on the VOMS.¹⁵ Moreover, research is needed to determine the lower age range in which the VOMS can be used reliably.

PRACTICAL IMPLICATIONS

1. This large sample of boys completed the VOMS without symptom provocation before their hockey season. The rates of symptom provocation were only 1% to 5% for each individual subtest and 10.6% for all subtests combined.
2. A substantial minority of this sample had near-point convergence ≥ 5 cm (22.3%).
3. Vestibular/ocular motor screening performance was minimally associated with age, concussion history, pre-existing headache or migraine conditions, pre-existing ADHD/LD, or history of anxiety or depression.
4. The findings suggest several positive qualities of the VOMS for the assessment and clinical management of pediatric concussion.

References

1. Cullen KE. The vestibular system: multimodal integration and encoding of self-motion for motor control. *Trends Neurosci.* 2012;35:185–196.
2. Khan S, Chang R. Anatomy of the vestibular system: a review. *NeuroRehabilitation.* 2013;32:437–443.
3. Baker RS, Epstein AD. Ocular motor abnormalities from head trauma. *Surv Ophthalmol.* 1991;35:245–267.
4. DiCesare CA, Kiefer AW, Nalepka P, et al. Quantification and analysis of saccadic and smooth pursuit eye movements and fixations to detect oculomotor deficits. *Behav Res Methods.* 2017;49:258–266.
5. Kraus MF, Little DM, Donnell AJ, et al. Oculomotor function in chronic traumatic brain injury. *Cogn Behav Neurol.* 2007;20:170–178.
6. Master CL, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. *Clin Pediatr (Phila).* 2016;55:260–267.
7. Murray NG, Ambati VN, Contreras MM, et al. Assessment of oculomotor control and balance post-concussion: a preliminary study for a novel approach to concussion management. *Brain Inj.* 2014;28:496–503.
8. Corwin DJ, Zonfrillo MR, Master CL, et al. Characteristics of prolonged concussion recovery in a pediatric subspecialty referral population. *J Pediatr.* 2014;165:1207–1215.
9. Corwin DJ, Wiebe DJ, Zonfrillo MR, et al. Vestibular deficits following youth concussion. *J Pediatr.* 2015;166:1221–1225.
10. Mucha A, Collins MW, Elbin RJ, et al. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med.* 2014;42:2479–2486.
11. Kontos AP, Sufrinko A, Elbin RJ, et al. Reliability and associated risk factors for performance on the vestibular/ocular motor screening (VOMS) tool in healthy collegiate athletes. *Am J Sports Med.* 2016;44:1400–1406.
12. Henry LC, Elbin RJ, Collins MW, et al. Examining recovery trajectories after sport-related concussion with a multimodal clinical assessment approach. *Neurosurgery.* 2016;78:232–241.
13. Scheiman M, Gallaway M, Frantz KA, et al. Nearpoint of convergence: test procedure, target selection, and normative data. *Optom Vis Sci.* 2003;80:214–225.
14. Yorke AM, Smith L, Babcock M, et al. Validity and reliability of the vestibular/ocular motor screening and associations with common concussion screening tools. *Sports Health.* 2017;9:174–180.
15. Moran RN, Covassin T, Elbin RJ, et al. Reliability and normative reference values for the vestibular/ocular motor screening (VOMS) tool in youth athletes. *Am J Sports Med.* 2018;46:1475–1480.
16. Worts PR, Schatz P, Burkhart SO. Test performance and test-retest reliability of the vestibular/ocular motor screening and king-devick test in adolescent athletes during a competitive sport season. *Am J Sports Med.* 2018;46:2004–2010.
17. Elbin RJ, Sufrinko A, Anderson MN, et al. Prospective changes in vestibular and ocular motor impairment after concussion. *J Neurol Phys Ther.* 2018;42:142–148.
18. Sufrinko AM, Kegel NE, Mucha A, et al. History of high motion sickness susceptibility predicts vestibular dysfunction following sport/recreation-related concussion. *Clin J Sport Med.* 2019;29:318–323.
19. 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;45:474–479.
20. Sufrinko AM, Marchetti GF, Cohen PE, et al. Using acute performance on a comprehensive neurocognitive, vestibular, and ocular motor assessment battery to predict recovery duration after sport-related concussions. *Am J Sports Med.* 2017;45:1187–1194.
21. Borsting E, Rouse M, Chu R. Measuring ADHD behaviors in children with symptomatic accommodative dysfunction or convergence insufficiency: a preliminary study. *Optometry.* 2005;76:588–592.
22. Bucci MP, Seassau M. Vertical saccades in children: a developmental study. *Exp Brain Res.* 2014;232:927–934.
23. Mostofsky SH, Lasker AG, Cutting LE, et al. Oculomotor abnormalities in attention deficit hyperactivity disorder: a preliminary study. *Neurology.* 2001;57:423–430.
24. 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;13:166–174.
25. Jacobson GP, Newman CW. The development of the dizziness handicap inventory. *Arch Otolaryngol Head Neck Surg.* 1990;116:424–427.
26. King D, Brughelli M, Hume P, et al. Concussions in amateur rugby union identified with the use of a rapid visual screening tool. *J Neurol Sci.* 2013;326:59–63.
27. Bonfield CM, Lam S, Lin Y, et al. The impact of attention deficit hyperactivity disorder on recovery from mild traumatic brain injury. *J Neurosurg Pediatr.* 2013;12:97–102.
28. Brooks BL, Iverson GL, Atkins JE, et al. Sex differences and self-reported attention problems during baseline concussion testing. *Appl Neuropsychol Child.* 2016;5:119–126.
29. Cook NE, Huang D, Silverberg N, et al. Concussion-like symptom reporting in high school student athletes with ADHD. *PM R.* 2016;8:S156.
30. Covassin T, Elbin R, Kontos A, et al. Investigating baseline neurocognitive performance between male and female athletes with a history of multiple concussion. *J Neurol Neurosurg Psychiatry.* 2010;81:597–601.
31. Elbin RJ, Kontos AP, Kegel N, et al. Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Arch Clin Neuropsychol.* 2013;28:476–484.
32. Iverson GL, Wojtowicz M, Brooks BL, et al. High school athletes with ADHD and learning difficulties have a greater lifetime concussion history. *J Atten Disord.* 2016. DOI: 10.1177/1087054716657410.
33. Littleton AC, Schmidt JD, Register-Mihalik JK, et al. Effects of attention deficit hyperactivity disorder and stimulant medication on concussion symptom reporting and computerized neurocognitive test performance. *Arch Clin Neuropsychol.* 2015;30:683–693.
34. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport, Zurich, November 2012. *J Athl Train.* 2013;48:554–575.
35. Glaviano NR, Benson S, Goodkin HP, et al. Baseline SCAT2 assessment of healthy youth student-athletes: preliminary evidence for the use of the child-SCAT3 in children younger than 13 years. *Clin J Sport Med.* 2015;25:373–379.
36. Snyder AR, Bauer RM; Health IFN. A normative study of the sport concussion assessment tool (SCAT2) in children and adolescents. *Clin Neuropsychol.* 2014;28:1091–1103.