Prospective Changes in Vestibular and Ocular Motor Impairment After Concussion

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Background and Purpose: The utility of prospective changes on the Vestibular/Ocular Motor Screening (VOMS) assessment are unknown, and 2 methods of scoring are published in the literature. Total scores are the total symptom scores for each VOMS component, and change scores are the difference between the pretest total symptom score and component total symptom scores. This study documented prospective changes in vestibular and ocular motor impairments and symptoms in high school athletes with concussion using the total and change scoring methods and compared the percentage of scores over clinical cutoffs using the total and change scoring methods for the VOMS.

Methods: Sixty-three athletes (15.53 ± 1.06 years) completed the VOMS at baseline (ie, preinjury), 1 to 7 days, and 8 to 14 days after concussion. A series of repeated-measures multivariate analyses of variance were conducted on total and change scores. A 2-way repeated-measures analysis of variance was performed on the near-point convergence distance. A series of χ^2 analyses compared scores exceeding clinical cutoffs between the total and change scoring methods.

Results: Total scoring revealed impairments (Wilks $\lambda = 0.39$, $F_{16,47} = 4.54$, $P < 0.001$, $\eta^2 = 0.61$) on all VOMS components at 1 to 7 and 8 to 14 days compared to baseline. Change scoring revealed postinjury impairments compared with baseline (Wilks $\lambda = 0.58$, $F_{14,49} = 2.52$, $P = 0.009$, $\eta^2 = 0.42$) on all components at 1 to 7 days; however, impairments at 8 to 14 days were revealed only for the vertical vestibular oculomotor reflex and vestibular motor sensitivity components. Total scoring identified significantly more scores over cutoffs at 1 to 7 days ($\chi^2_{1,63} = 5.97$, $P = 0.02$) compared with change scores.

Discussion and Conclusions: Both total and change scoring methods on the VOMS are useful for identifying impairments following concussion.

Video Abstract available for more insights from the authors (see Supplemental Digital Content 1, http://links.lww.com/JNPT/A230)

Key words: *brain, human movement system, sport, VOMS, youth*

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INTRODUCTION

Sports-related concussion (SRC) is a heterogeneous injury characterized by a wide range of symptoms and impairments that require a comprehensive assessment approach.[1-3] Concussion consensus statements encourage the use of assessments that measure multiple domains, including symptom reports, neurocognitive function, and balance performance, in conjunction with a detailed clinical examination and interview.[3-6] Many SRC assessments such as cognitive testing[7] and symptom reports[8] are best administered in a prospective method (ie, baseline/pretest, posttest) that allows for each athlete with concussion to serve as his or her own noninjured control.[7,9,10] This approach allows for the comparison of postinjury data with baseline data. Researchers have documented pre- to postinjury changes in symptoms,[11] neurocognitive,[12,13] and balance performance.[14]

The evaluation of vestibular and ocular motor systems is an important part of the clinical assessment for SRC. Abnormal vestibular function occurs in 61% of pediatric patients with concussion,[15] and more than 90% of children with post-concussion dizziness exhibited at least 1 abnormal finding on a balance and vestibular evaluation.[16] Near-point convergence (NPC) insufficiency occurs in 42% to 49% of athletes with SRC.[17,18] Until recently, the evaluation of the vestibular and oculomotor system required specialty referral and sophisticated assessments (eg, video nystagmography) that were not feasible to medical professionals (physicians, physical and occupational therapists) working in many rehabilitation settings. In an effort to address this need, the Vestibular/Ocular Motor Screening (VOMS)[15] was developed to assess symptom provocation elicited from a series of vestibular and ocular motor tasks (eg, saccades and vestibular oculomotor reflex [VOR]).

The VOMS is a unique measure of vestibular and ocular motor impairment and symptoms that is distinct from other vestibulospinal/balance (eg, Balance Error Scoring System [BESS])[15,19] and ocular motor assessments (eg, the King-Devick Test).[19] The VOMS is a symptom provocation measure comprising 4 oculomotor components (smooth pursuits, horizontal and vertical saccades, NPC distance, and symptoms) and 3 vestibular components (horizontal and vertical vestibular ocular reflex and visual motion sensitivity [VMS]). Before administering the VOMS, athletes rate their headache, dizziness, nausea, and fogginess on a 10-point Likert scale (0 "none" to 10 "severe"). After completing each VOMS component, the athlete rates symptoms again. Both NPC distance and symptoms are also assessed. A total symptom score of 2 or more on any one VOMS component and NPC distance of 5 cm or more distinguish athletes with SRC from controls.[15] The VOMS differs from other measures of oculomotor function such as the King-Devick Test, which predominantly evaluates saccadic eye movements via a rapid number naming task, in that it provides a more comprehensive evaluation of oculomotor function such as convergence and pursuits as well as an evaluation of vestibular function (ie, vestibular ocular reflex). The VOMS is successful in identifying athletes with SRC from controls without concussion, with a combined sensitivity of 89% for 3 of its components (eg, vestibular ocular reflex, visual motor sensitivity, and NPC distance)[15] and false-positive rates of 7% in a sample of college athlete without concussion.[20] There is high internal consistency for VOMS items in athletes with concussion ($\alpha = 0.92$)[15] and athletes without concussion ($\alpha = 0.97$).[20] Anzalone et al[21] reported that impairments on all VOMS items, except NPC distance, were associated with a delayed SRC recovery. Despite the growing empirical support for the VOMS, researchers have yet to examine changes in VOMS scores from baseline to postconcussion time points. Determining pre- to postinjury changes on the VOMS will help determine the amount of impairment that is observed following SRC in comparison with preinjury levels of functioning.

Prospective changes from baseline to postconcussion in vestibular and ocular motor symptoms and impairment are unknown. Examining prospective changes in vestibular and ocular motor impairment and symptoms using the VOMS requires the consideration of the 2 scoring methods published in the literature. This information will further validate the role that vestibular and oculomotor assessment has following SRC, better isolate the effects of SRC while controlling for preexisting conditions (eg, undiagnosed vestibular and/or ocular motor disorders), and inform methods of administration for the VOMS for SRC. Some researchers have reported total symptom scores for each of the 7 VOMS components (ie, possible score for each component is 0-40),[15,20,21] whereas others (Yorke et al[19]) reported change scores for each of the 7 VOMS components (ie, the difference between total symptom score for each component and pretest total symptom score [range of change scores for each component is 0-10]). The assessment of change between patient scores and/or reports before and after a clinical examination is often employed with other vestibular assessments such as the motion sensitivity test[22] and the dynamic visual acuity test.[23] Thus, the primary purpose of the current study was to document prospective changes in vestibular and ocular motor impairment and symptoms in high school athletes with SRC using both total and change scoring methods for the VOMS. The secondary purpose of this study was to compare the percentage of athletes scoring over clinical cutoffs prior to the athletic season and after SRC, using both total and change scoring methods for the VOMS.

METHODS

Design and Participants

A prospective, repeated-measures (ie, baseline, 1-7, 8-14 days) design was used for this study. High school athletes aged 14 to 18 years with a medically diagnosed SRC were recruited from SRC research surveillance programs in the Midwest and Central Midwest regions of the United States. The inclusion criteria for this study included sustaining a concussion during sports participation, speaking English as primary language, and the completion of all 3 study time points. Any athlete not completing study visits (ie, missing data) was excluded, as well as those reporting a history of learning disability (LD), attention-deficit/hyperactivity disorder (ADHD), treatment of headaches/migraines, moderate to severe traumatic brain injury, neurological disorder, or psychological disorder.

Measures

Concussion Definition and Diagnosis

Concussions were assessed by certified athletic trainers or sports medicine physicians using the following criteria: (1) observed and/or reported mechanism of injury; and (2) the presence of at least 1 or more of the following: (*a*) on-field signs (eg, disorientation/confusion, loss of consciousness, balance difficulties, amnesia), (*b*) symptoms (dizziness, nausea, headache), and/or (c) any impairment on sideline assessments (eg, Sport Concussion Assessment Tool [SCAT3]).

Vestibular/Ocular Motor Screening

The VOMS comprises 9 components that include (1) baseline symptoms, (2) smooth pursuits, (3) horizontal saccades, (4) vertical saccades, (5) horizontal VOR, (6) vertical VOR, (7) VMS, (8) NPC distance, and (9) convergence symptoms. The baseline symptoms for VOMS components are referred to pretest VOMS symptoms for clarity in this study. Prior to administration, the athlete rated current pretest symptoms that consisted of headache, dizziness, nausea, and fogginess on a 10-point Likert scale (0 "none" to 10 "severe"). After completing each VOMS component, the athletes rated their headache, dizziness, nausea, and fogginess. The NPC distance was the average distance (cm) across 3 trials. The scoring sheet for the VOMS is published as online supplemental material in Mucha et al.[15]

Procedures

Approval for the study was obtained from the University of Arkansas institutional review board. After obtaining consent/assent, all athletes were administered the VOMS by a trained researcher as part of a sports preparticipation physical examination. The sports medicine professionals referred all athletes with SRC to the research team for additional testing.

Athletes with concussion were readministered the VOMS by a trained researcher at 1 to 7 and 8 to 14 days following injury. Because of variations in the scheduling of data collection visits, it was not feasible for the same trained researcher to conduct all 3 assessments on the same athlete with concussion. The researcher did not have access to the VOMS scores for the previous visit prior to each data collection session.

Data Analysis

Descriptive statistics (means, standard deviations, frequencies, percentages) were used to describe the characteristics of the sample. Total symptom scores were calculated for each VOMS component (eg, vertical VOR) by summing the individual symptom scores for headache, nausea, dizziness, and fogginess symptoms.[15,20,21] In addition, a change score was calculated for each VOMS component by taking the total symptom score for that component and then subtracting the total symptom score from the pretest symptom score.[19] For example, an athlete reporting a total pretest VOMS symptom score of 5 and a total symptom score of 7 on the smooth pursuit component had a change score of 2 for that component. Any change score that was negative (ie, the total symptom score is less than the pretest VOMS score) was coded as a zero and assumed not to provoke the athlete. To examine changes in vestibular and oculomotor function across time (ie, baseline, 1-7 days, and 8-14 days postinjury), a series of repeated-measures multiple analyses of variance (MANOVAs) were performed on both total and change scores for each VOMS component (smooth pursuits, horizontal and vertical saccades, horizontal and vertical VOR, VMS, and NPC symptom) except NPC distance (see the following text). Follow-up post hoc repeated-measures analyses of variance (ANOVAs) were performed on each VOMS component to examine differences at each time point. A 1-way repeated-measures ANOVA was performed for NPC distance. The dependent variable was the NPC distance (cm), and the independent variable was time (baseline, 1-7 days, and 8-14 days). A series of χ^2 analyses were conducted to statistically compare the number of athletes with scores exceeding clinical cutoff scores of 2 or more on any VOMS component and/or an NPC distance of 5 cm or more (as determined by Mucha et al[15]) at each time point for both total and change scoring methods. Except when corrected for multiple comparisons, statistical significance for all tests was set at $P \leq 0.05$.

RESULTS

Participants

Eighty-three athletes sustained an SRC and were referred for testing. Approximately 8% (10/83) of the sample reported a history of LD/ADHD; 6% (5/83) reported a history of headache and/or migraine treatment, and 6% (5/83) did not complete all postinjury visits and were excluded from the final sample. The final sample included 63 of 83 (76%) high school athletes with concussion comprising 44 (70%) males and 19 (30%) females. The average age was 15.53 ± 1.06 years, and 32% (20/63) reported a history of at least 1 SRC. The mean number of days between the date of injury and the first and second posttest visits was 5.02 ± 1.73 days and 11.70 ± 1.95 days, respectively. The representation of sports was as follows: football, 67% (42/63); competitive cheer, 13% (8/63); basketball, 8% (5/63); soccer, 6% (4/63); and wrestling, 6% (4/63).

Analysis of VOMS Total Scores and NPC Distance

The repeated-measures MANOVA revealed a significant within-subjects main effect for time on the total scores for VOMS components (Wilks $\lambda = 0.39$, $F_{16,47} = 4.54$, $P < 0.001$, $\eta^2 = 0.61$). Post hoc repeated-measures ANOVAs revealed significant differences for pretest VOMS symptoms ($F_{2,124} = 46.45$, $P < 0.001$, $\eta^2 = 0.43$), smooth pursuits ($F_{2,124} = 40.33$, $P < 0.001$, $\eta^2 = 0.39$), horizontal saccades ($F_{2,124} = 51.98$, $P < 0.001$, $\eta^2 = 0.46$), vertical saccades ($F_{2,124} = 51.94$, $P < 0.001$, $\eta^2 = 0.46$), NPC symptoms ($F_{2,124} = 50.05$, $P < 0.001$, $\eta^2 = 0.45$), horizontal VOR ($F_{2,124} = 45.52$, $P < 0.001$, $\eta^2 = 0.42$), vertical VOR ($F_{2,124} = 46.67$, $P < 0.001$, $\eta^2 = 0.43$), and VMS ($F_{2,124} = 46.36$, $P < 0.001$, $\eta^2 = 0.43$). Subsequent pairwise comparisons revealed significant differences for each VOMS component score across time (see Table 1). Specifically, total symptom scores at 1 to 7 and 8 to 14 days postinjury were significantly higher than the baseline time point for all VOMS components. The results from a repeated-measures ANOVA

Table 1. Means and Standard Deviations for VOMS Total Scores and NPC Distance at Baseline, 1-7 Days, and 8-14 Days Postconcussion (n = 63)

	Baseline		1-7 d		8-14 d	
VOMS Component	***M***	**SD**	***M***	**SD**	***M***	**SD**
Pretest VOMS symptoms	0.17	0.64	6.25[a]	6.53	1.35[b]	2.50
Smooth pursuits	0.23	0.69	6.51[a]	6.64	1.70[b]	3.99
Horizontal saccades	0.33	0.95	7.33[a]	7.01	1.65[b]	2.90
Vertical saccades	0.32	0.86	7.74[a]	7.56	1.67[b]	2.86
NPC symptoms	0.29	0.73	7.63[a]	7.53	1.92[b]	3.58
Horizontal VOR	0.62	1.44	8.11[a]	8.03	2.24[b]	3.64
Vertical VOR	0.54	1.34	8.29[a]	8.35	2.38[b]	3.96
VMS	0.60	1.32	8.79[a]	8.47	2.52[b]	4.29
NPC distance, cm	1.63	2.74	5.51[a]	6.78	3.23[b]	3.98

Abbreviations: NPC, near-point convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Oculomotor Screening; VOR, vestibular oculomotor reflex.
[a]$P \leq 0.001$, significantly different from baseline.
[b]$P \leq 0.05$, significantly different from baseline.

for NPC distance revealed a significant within-subjects main effect for time (Wilks $\lambda = 0.66$, $F_{2,61} = 15.55$, $P < 0.001$, $\eta^2 = 0.34$), and NPC distance was significantly higher than baseline at 1 to 7 days ($P < 0.001$) and 8 to 14 days ($P = 0.008$) (see Table 1).

Analysis of VOMS Change Scores

The repeated-measures MANOVA for VOMS change scores revealed a significant within-subjects main effect for time (Wilks $\lambda = 0.58$, $F_{14,49} = 2.52$, $P = 0.009$, $\eta^2 = 0.42$). Post hoc repeated-measures ANOVAs revealed significant differences for horizontal saccades ($F_{2,124} = 9.08$, $P = 0.001$, $\eta^2 = 0.13$), vertical saccades ($F_{2,124} = 17.54$, $P < 0.001$, $\eta^2 = 0.22$), NPC symptoms ($F_{2,124} = 11.87$, $P < 0.001$, $\eta^2 = 0.16$), horizontal VOR ($F_{2,124} = 11.40$, $P = 0.001$, $\eta^2 = 0.16$), vertical VOR ($F_{2,124} = 13.39$, $P < 0.001$, $\eta^2 = 0.18$), and VMS ($F_{2,124} = 16.91$, $P < 0.001$, $\eta^2 = 0.21$). There was not a significant within-subjects main effect for time for the smooth pursuit VOMS component change scores ($F_{2,124} = 0.48$, $P = 0.61$, $\eta^2 = 0.01$). Post hoc univariate analyses revealed that change scores were significantly higher at 1 to 7 days postinjury than at baseline for all VOMS components except smooth pursuits ($P = 0.75$). At the 8- to 14-day time point, only the vertical VOR ($P = 0.02$) and the VMS ($P = 0.05$) components were significantly different from those that at baseline (see Table 2).

Comparison of Athletes Exceeding Clinical Cutoffs on VOMS Between Total Score and Change Score Approaches

The number of athletes exceeding VOMS clinical cutoff scores of 2 or more on any component and/or an NPC distance of 5 cm or more (as determined by Mucha et al[15]) was compared for each time point. There were no significant differences in the number of athletes scoring over clinical cutoffs using the total or change scoring methods at the baseline ($\chi^2_{1,63} = 0.21$, $P = 0.65$) and 8- to 14-day time points ($\chi^2_{1,63} = 0.88$, $P = 0.35$). However, the total scoring method identified significantly more athletes over cutoffs than the change scoring method at 1 to 7 days postinjury ($\chi^2_{1,63} = 5.97$, $P = 0.02$). A comparison of the percentage of athletes scoring above clinical cutoffs across time periods is presented in Table 3.

Symptom Improvement on the VOMS

A small percentage of athletes exhibited a resolution or improvement in symptoms following the completion of a VOMS component when compared with their pretest VOMS symptoms. At the baseline time point, 3% (2/63) of athletes reported symptom improvement on any VOMS component. In addition, 21% (13/63) and 8% (5/63) of the sample reported symptom improvement at 1 to 7 days and 8 to 14 days, respectively.

DISCUSSION

The current study is the first to document prospective changes in vestibular and ocular motor symptoms and impairment in high school athletes before and after SRC. These prospective changes were also examined using previously published total[15,20] and change scoring methods[19] for the VOMS. The main finding of this study is that compared with preinjury functioning, vestibular and ocular motor functioning is impaired following SRC. These impairments are particularly evident during the first week following injury. In comparison with baseline scores, both the total and change scoring methods for the VOMS revealed significant impairment at 1 to 7 days postinjury. However, at 8 to 14 days postconcussion, the number of VOMS items showing significant impairment compared with baseline differed between the total and change scoring methods. More specifically, the change scoring method revealed impairment on the VOMS for 2 components (vertical VOR and VMS) at 8 to 14 days following SRC. In contrast, the total scoring method revealed impairment for all VOMS items at 8 to 14 days postinjury.

Compared with the total scoring method, the change scoring method resulted in a decrease of 20% and 8% in the number of scores above clinical cutoffs[15] at 1 to 7 days and 8 to 14 days, respectively. As a result of the well-documented increases in symptomatology following SRC,[24,25] the change score method may be a truer measure of symptom provocation on the VOMS. In contrast, without considering the athlete's pretest VOMS symptoms, the total scoring method may inappropriately classify an athlete as provoked following a VOMS component. Moreover, as it is appropriate to target rehabilitative approaches to areas of functioning that are slower to recover,[1,2] the VOMS change scores may more accurately reflect ongoing deficits that will better focus interventions and

Table 2. Means and Standard Deviations for VOMS Change Scores and NPC Distance at Baseline, 1-7 Days, and 8-14 Days Postconcussion (n = 63)

	Baseline		1-7 d		8-14 d	
VOMS Components	***M***	**SD**	***M***	**SD**	***M***	**SD**
Smooth pursuits	0.06	0.30	0.48	0.96	0.40	2.52
Horizontal saccades	0.17	0.61	1.17[a]	2.05	0.30	0.71
Vertical saccades	0.17	0.68	1.53[b]	2.31	0.33	0.76
NPC (Sx)	0.14	0.50	1.54[a]	2.09	0.62	1.47
Horizontal VOR	0.46	1.04	1.94[a]	2.60	0.91	1.57
Vertical VOR	0.40	0.99	2.16[b]	2.94	1.05[a]	1.92
VMS	0.43	0.89	2.63[b]	3.13	1.21[a]	2.22

Abbreviations: NPC, near-point convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Oculomotor Screening; VOR, vestibular oculomotor reflex.
[a]$P \leq 0.05$, significantly different from baseline.
[b]$P \leq 0.001$, significantly different from baseline.

Table 3. The Percentage of Athletes Scoring Above Clinical Cutoffs for VOMS Total Symptoms, VOMS Change Scores, and NPC Distance Across Time Periods[a] (n = 63)

	Total Scores	Change Scores	NPC Distance	(Combined Total and NPC Distance)	(Combined Change and NPC Distance)
Baseline	21% (13/63)	18% (11/63)	3% (2/63)	24% (15/63)	21% (13/63)
1-7 d	76% (48/63)	56% (35/63)	38% (24/63)	86% (54/63)	68% (43/63)
8-14 d	38% (24/63)	30% (19/63)	18% (11/63)	44% (28/63)	38% (24/63)

Abbreviations: NPC, near-point convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Oculomotor Screening.

[a]A combined percentage of athletes with VOMS total scores, change scores, and/or NPC distance is also presented at baseline, 1-7 days, and 8-14 days following sports-related concussion. Change scores were not calculated for NPC distance. This component is not assessed prior to the administration of the VOMS.

treatment. This method of accounting for pretest symptoms when scoring the VOMS should also increase the accuracy of clinical interpretation by minimizing the effects of undiagnosed preexisting conditions and disorders (ie, female sex and history of motion sensitivity[20]) that are reported to influence vestibular and ocular motor functioning.

The pre- to postinjury changes in vestibular and oculomotor impairment and symptoms reported in the current study are in concordance with other studies that document prospective change on other SRC assessments. Postconcussion impairment relative to baseline levels of neurocognitive performance has been documented at 1 and 2 weeks following SRC.[11,12,26,27] Deficits in postural stability (ie, BESS) are reported to be worse during the first 3 to 5 days following injury.[28] Similarly, an increase in postconcussion symptom reports is well documented in the literature during the first week following SRC and may persist for several weeks.[8,27] The documentation of pre- to postinjury changes in vestibular and oculomotor symptoms and impairment supports the VOMS as a part of the recommended multifaceted approach for SRC assessment.

Thirty-five percent of the current sample reported baseline VOMS total symptom scores above clinical cutoffs (eg, excluding NPC distance), which is higher than the 11% previously reported in a sample of college-aged athletes.[20] The discrepancy between these findings could be due to several factors that include the possibility of a premorbid history of motion sensitivity, undiagnosed vestibular/oculomotor disorder, and/or higher symptom reporting behaviors in adolescent athletes compared with college athletes. Unlike Kontos et al,[20] the current study did not gather data on a preexisting history of motion sensitivity, which was a significant predictor of baseline VOMS total scores exceeding clinical cutoffs. The estimated prevalence of vestibular disorders in children and adolescents is reported to range up to 15%,[29-31] and 25% of the individuals aged 6 to 18 years require corrective lenses.[32] Moreover, high baseline symptom reporting is observed in adolescent athletes without concussion. In a large sample of adolescent athletes without concussion (ie, >30 000), Iverson et al[33] reported that 28% of adolescent girls and 19% of adolescent boys reported symptoms meeting criteria for postconcussion syndrome (eg, *International Classification of Diseases, Tenth Revision*). Asken et al[34] reported that 20.3% of adolescents without concussion reported symptoms that classify as postconcussion syndrome. The possible combination of undiagnosed vestibular and oculomotor disorders and the high symptom reporting in adolescents could account for the higher percentage of athletes in the current study exceeding clinical cutoffs.

The inconsistent and variable nature of symptom reporting in high school athletes is well documented in the literature[33,34] and should be considered when using symptom provocation assessments such as the VOMS in clinical practice. According to clinical observations, some athletes report fewer symptoms (ie, symptom improvement) following the completion of a VOMS component compared with their pretest VOMS levels. The current study revealed that this percentage of athletes was relatively low at baseline (3%), increased to 21% during the first week after injury, and decreased to 8% of the sample at 8 to 14 days. There is no physiological explanation for why symptoms would resolve in healthy athletes completing the VOMS at baseline other than the inconsistency of assessing symptoms in adolescent athletes.[33]

Strengths and Limitations

There are several strengths and limitations to the current study. This study directly compares the total and change scoring methods currently published in the literature on the VOMS and documents unusual symptom reporting behaviors (ie, symptom resolution on the VOMS) that may or may not be indicative of SRC in adolescent athletes. Data were collected at fairly large time intervals lapsing acute and subacute time points. Recently, females were reported to have increased VOR impairment compared with males[35] and female sex was associated with a greater likelihood of exhibiting VOMS scores over clinical cutoff levels following SRC.[20] However, these findings used total scoring methods and additional research is needed to examine whether these differences exist when data are analyzed with the change scoring approach. Medical information pertaining to preexisting vestibular disorders or motion sensitivity that are related to abnormal baseline scores on the VOMS[20] and measures of postural instability[36] was not collected for this sample. Athletes with a history of migraine, LD, and ADHD were excluded from the study, and findings may not be generalizable to these subpopulations. Moreover, concussion history and medication use were not included in the analyses, which should be examined in future studies. Data regarding activity level (eg, level of physical exertion permitted) or treatment (eg, academic accommodations) following SRC were not collected, which may directly influence improvement or exacerbation of vestibular dysfunction.[37] The current clinical cutoffs published by Mucha et al[15] were derived from total scores rather than change scores from their sample. These clinical cutoffs have not yet been validated in a separate sample or replicated using change scores. Moreover, inter- and intrarater reliability was not recorded in the current study, nor published in previous literature. Given the frequent serial administration of the VOMS throughout SRC recovery, documenting intra- and interrater reliability for this measure is warranted.

Future Research and Clinical Implications

The current study highlights several clinical research questions that warrant attention to advance further the clinical utility and application for the VOMS in athletes with SRC. The current study included a baseline (ie, preinjury) assessment, which may be confused with the "baseline symptoms" that are actually part of the VOMS assessment form. Therefore, we recommend renaming this part of the VOMS assessment as "pretest VOMS symptoms," which should eliminate any confusion for clinicians, researchers, and patients. In addition, based on the current findings, clinicians and researchers can account for and control the influence of the athlete's current symptom status by employing a change scoring method for the VOMS. Future research should investigate how to determine clinically meaningful change for each VOMS component and develop new clinical cutoffs using the change score method as opposed to previous cutoffs that were only based on postinjury scores (eg, Mucha et al,[15]). Finally, the underlying reasons for symptom improvement on the VOMS in some patients are unclear and warrant further exploration.

CONCLUSIONS

Vestibular and ocular motor impairment and symptoms are exacerbated compared with baseline scores following SRC in high school athletes. However, the majority of these vestibular and ocular motor impairments and symptoms resolve within 14 days following injury. Clinicians should consider an athlete's pretest VOMS symptom score when administering and interpreting postinjury VOMS scores. The use of a tool such as the VOMS that is specific to vestibular and oculomotor impairment and symptoms related to SRC is an important component of a comprehensive assessment of SRC and reflects emerging clinical profiles-based approaches to conceptualizing and treating patients with this injury. Overall, the results from the current study expand the clinical utility of the VOMS and offer empirical evidence for the use of VOMS change scores in addition to postinjury VOMS scores.

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