Virtual Reality Application for Vestibular/Ocular Motor Screening: Current Clinical Protocol Versus a Novel Prototype

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Background: Virtual reality (VR) has been explored to improve baseline and postinjury assessments in sport-related concussion (SRC). Some experience symptoms related to VR, unrelated to concussion. This may deter use of vestibular/ocular motor screening (VOMS) using VR. Baseline VR VOMS symptomatology differentiates baseline from overall symptomatology.

Hypothesis: There will be no difference between current clinical manual VOMS (MAN), a clinical prototype (PRO), and VR for symptom provocation change score (SPCS) and near point of convergence (NPC) average score in a healthy population and sex differences among the 3 modes of administration.

Study Design: Cohort study.

Level of Evidence: Level 3.

Methods: A total of 688 National Collegiate Athletic Association Division I student-athletes completed VOMS using 3 methods (MAN, N = 111; female athletes, N = 47; male athletes, N = 64; average age, 21 years; PRO, N = 365; female athletes, N = 154; male athletes, N = 211; average age, 21 years; VR, N = 212; female athletes, N = 78; male athletes, N = 134; average age = 20 years) over a 3-year period (2019-2021) during annual baseline testing. Exclusion criteria were as follows: self-reported motion sickness in the past 6 months, existing or previous neurological insult, attention deficit hyperactivity disorder, learning disabilities, or noncorrected vision impairment. Administration of MAN followed the current clinical protocols, PRO used a novel prototype, and VR used an HTC Vive Pro Eye head mounted display. Symptom provocation was compared using Mann-Whitney *U* tests across each VOMS subtest with total SPCS and NPC average by each method.

Results: MAN had significantly ($P < 0.01$) more baseline SPCS (MAN = 0.466 ± 1.165, PRO = 0.163 ± 0.644, VR = 0.161 ± 0.933) and significantly ($P < 0.01$) and more SPCS (MAN = 0.396 ± 1.081, PRO = 0.128 ± 0.427, VR = 0.48 ± 0.845) when compared with PRO and VR. NPC average measurements for VR (average, 2.99 ± 0.684 cm) were significantly greater than MAN (average, 2.91 ± 3.35 cm; $P < 0.01$; Cohen's d = 0.03) and PRO (average, 2.21 ± 1.81 cm; $P < 0.01$; Cohen's d = 0.57). For sex differences, female athletes reported greater SPCS with PRO (female athletes, 0.29 ± 0.87; male athletes, 0.06 ± 0.29; $P < 0.01$) but not in VR or MAN.

Conclusion: Using a VR system to administer the VOMS may not elicit additional symptoms, resulting in fewer false positives and is somewhat stable between sexes.

Clinical Relevance: VOMS may allow for standardization among administrators and reduce possible false positives.

Keywords: baseline; concussion; virtual reality; VOMS

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Concussion remains an active public health concern that accounts for 5% to 9% of all sports-related injuries.[23,24] Injury classification of sport-related concussion (SRC) is difficult due to the heterogeneity of clinical presentation, and its proper diagnosis requires highly trained clinicians.[23] This is especially concerning given that one-third of all secondary schools in the United States do not have access to a certified athletic trainer and this could result in numerous missed diagnoses.[16] Athletic trainers are frontline healthcare professionals who provide critical, immediate, and follow-up care for SRC. The lack of appropriate personnel, such as an athletic trainer, in sporting events at the secondary school level, makes the diagnosis and treatment of SRC quite difficult. Fortunately, assessments of the vestibular and visual system are emerging as the measure to detect an SRC.[42] The vestibular/ocular motor screening (VOMS) examination has high diagnostic accuracy (sensitivity, 0.89),[19,29] and it is among the most informative tools in a clinician's toolbox for a cost-effective, quick, and reliable diagnosis of SRC without the need for further testing.

The VOMS assesses symptom provocation of the vestibular and ocular system via a series of subtests.[29,32] This includes evaluating smooth pursuits, horizontal and vertical saccades, near point of convergence (NPC), horizontal and vertical vestibular/ocular reflex, and visual motion sensitivity. Traditionally, the VOMS is administered using the clinician's fingers on each hand or 2 tongue depressors with a 14-point black dot at one end, a metronome application, and a metric linear ruler. Due to the minimal equipment required and ease of use, it is an ideal tool in any clinical, field, or sideline setting. The administration and interpretation of the VOMS relies heavily upon appropriately trained personnel and subjective symptom reporting. For example, the horizontal saccades component of the VOMS requires the eyes to travel between 2 fixed positions for 10 rapid repetitions at exactly 3 feet away from the patient, 1.5 feet to the right and the left of the patient's midline. At the successful conclusion of this task, the patient rates their overall headache, dizziness, nausea, and fogginess. These exact locations of the administrator's fingers or implementation device are intended to create a gaze angle of 30°.[29] If the distance the eye must travel is not consistent, it will subsequently alter the gaze angle along with potentially changing the overall symptoms reported.[10,29,39] It is important to properly administer the examination to ensure an appropriate diagnosis and management when dealing with an injury as critical as SRC. To the authors' best knowledge, no tools exist to aid in standardizing the administration of the VOMS to reduce overall administrator error and record accurate symptoms beyond an NPC ruler,[3,32] which is a custom-created device not sold commercially,[32] and augmented reality.[22] It is important to explore how tools that attempt to standardize the VOMS may be used to inform clinical practice. However, these should be properly vetted using baseline data before determining efficacy and safety.

Recent advances in virtual reality (VR) technology have increased our ability to standardize particular examinations and increase user enjoyment.[8,25] Moreover, numerous VR systems can track the eyes during stimuli presentation,[1,2] which can enhance the objectivity of subjective symptom report examinations. Assessments of the oculomotor function appear to be a promising direction for the early diagnosis of SRC[14,31,33] and may be promising tools to aid in the pursuit of rehabilitation services.[4,40] While advantageous, some persons may experience VR sickness (ie, dizziness and nausea) while engaging in VR due to the virtual environment or the type of equipment used to present the stimuli.[5,17,34,36] In fact, up to 67% of adults may experience mild-to-severe symptoms of VR sickness,[5] with women being more likely to experience VR sickness compared with men.[11–13,30,35] Before using VR as a major platform for standardizing symptom-provoking vision exams like the VOMS, it is important to ascertain how healthy persons and specific genders may respond. This is a critical first step before implementation in disease populations. The purpose of this article is to assess the differences between the current clinical standard manual VOMS assessment, the use of a novel prototype, and a novel VR platform for VOMS assessment at baseline. A secondary purpose is to examine how the different sexes may respond to these various VOMS modalities. It is hypothesized that there will be no difference in symptom provocation with the administration of the VOMS protocol with all 3 platforms with the overall population and between sexes. It is also hypothesized that there will be no difference in NPC measurements with all 3 platforms.

METHODS

Participants

The study included 688 National Collegiate Athletic Association (NCAA) Division I healthy student-athletes who were a convenience sample that consisted of 3 groups: 111 (female athletes, N = 47; male athletes, N = 64; average age, 21 years) who completed the manual VOMS (MAN), 365 healthy young adults (female athletes, N = 157; male athletes, N = 211; average age, 21 years) who completed the VOMS administered with a novel prototype (PRO), and 212 healthy young adults (female athletes, N = 78; male athletes, N = 134; average age, 20 years) who completed the VOMS administered with the VR system. All participants were free of existing or previously diagnosed neurological injury (including SRC), attention deficit hyperactivity disorder, learning disabilities, noncorrected vision impairment, motion sickness (within the past 6 months), and any lower extremity injury that can impair the ability to stand upright as determined by self-report. All participants were individual observations collected at preparticipation physical examinations. All participants provided written informed consent to the study procedure, which was approved by the University's Institutional Review Board, before enrollment into the study. VOMS was administered at the University of Nevada, Reno campus.

Procedures

VOMS Administered Manually With Handheld Targets

The current clinical assessment of the VOMS involves an administrator assessing baseline symptoms, which consisted of headache, nausea, dizziness, and fogginess.[29] Participants were asked to state the severity of each symptom based on a scale of 0 to 10 before the start of the VOMS assessment and after each subtest of the VOMS. The equipment used for the manual (MAN) VOMS consists of 2 targets made from a wood tongue depressor with a 14-point black dot at one end, a metronome application, and a metric linear ruler. The VOMS tests were administered by 5 trained administrators who were evaluated by the principal investigator as being the most consistent and reliable, as determined by subjective analysis. The subtests were administered as follows according to literature standards[10,26,28,29,32]:

Smooth Pursuits. For smooth pursuits, the subject would sit in a designated chair and the administrator would hold the target in front of the subject's face at a distance of 3 feet. This distance was estimated by the administrator. The subject was instructed to focus on the target with their eyes and follow the target while keeping their head motionless. The administrator would move the target in an "H" pattern. This pattern runs 3 feet horizontally and 3 feet vertically. These distances were estimated by the administrator.

Saccades. The administrator holds up the 2 targets and instructs the subject to keep their head still while moving their eyes from 1 target to the other to the beat of a metronome app set at 180 beats per minute. The targets are held 3 feet apart, which is again estimated by the administrator. This is performed both horizontally (H_Saccades) and vertically (V_Saccades) as separate tests for a total of 10 repetitions, where 1 repetition is over and back with the eye movement.

Near Point of Convergence. The subject is given a target to hold. They are instructed to hold the target at arm's length, at the height of their nose. Fixating on the target with both eyes, they bring the target slowly to their nose. They are instructed to stop the target the moment they see 2 targets instead of 1. This distance is measured with the metric measuring device in centimeters from the tip of the nose to the target. This is repeated 3 times and each measurement is recorded. A symptom assessment is taken after the third trial of NPC.

Vestibular Ocular Reflex. The administrator holds 1 target in front of the subject's face at a distance of 3 feet. This distance is estimated by the administrator. The subject is instructed to fixate with their eyes on the target while rotating their head side to side at a 30° angle from midpoint to the beat of a metronome app set at 180 beats per minute for a total of 10 repetitions; 1 repetition is over and back with the head movement. This was performed both horizontally (H_VOR) and vertically (V_VOR) as separate tests.

Visual Motion Sensitivity. The subject is asked to stand and is given one of the targets. They are instructed to hold the target at arm's length at the height of their nose. They are instructed to fixate with their eyes on the target while rotating their upper body in a 180° motion (from one hip to the other). They are instructed to do this to the beat of the metronome app set at 50 beats per minute. This is done for 10 repetitions where 1 repetition is over and back.

VOMS Using Novel Prototype

Symptomology and NPC data were collected using the VOMS assessment with a novel prototype (PRO).[1] This prototype was constructed to standardize the targets for the administration of the 7 tests within the VOMS (Figures 1 and 2). This adjustable height stand (labeled B in Figure 1) incorporates a mobile cross arm (labeled A in Figure 1). The cross arm has 14-point targets positioned at midpoint and both ends. One end of the cross arm has an extendible inner calibrated arm with a movable target for NPC measurement (labeled D in Figure 1). The base has a measuring tape to ensure the subject is 3 feet from the center of the base (labeled C in Figure 1). A tablet holder enables the test administrator to record symptom data and use a metronome application for the saccades, VOR, and VMS tests (Figure 1).

VOMS Using a VR System

The VOMS protocol administered in VR was conducted with an HTC Vive Pro Eye head-mounted display (HMD) with a diagonal focus of vision (FOV) of 110°, refresh rate of 90 Hz, a combined resolution of 2880 × 1600 pixels, 6 degrees of freedom for position and orientation tracking, and adjustable interpupillary and focal distances. Before beginning the examination, the participant's nose length was measured and recorded to account for HMD being mounted onto the head. The headset was powered by an Acer Predator gaming laptop with a seventh-Generation Intel Core i7 Quad-Core processor with 16 GB of memory and NVIDIA GeForce GTX 1070 graphics card running Windows 10. The HTC VIVE 2.0 Hand Controller was used to receive input from participants to start the stimuli moving toward them and stop the stimuli when ocular convergence was lost (image splitting into 2 objects) during the NPC test and to recreate the target object during the VMS component of the VOMS. The Unity3D engine Version 2019.1.6 and the Unity3D VR plugin SteamVR – Version 1.7 were used to develop the VOMS stimuli in which the VOMS protocol was simulated in a VR environment. HTC's Sranipal SDK Version 1.1.0.1 was used to read eye-tracking data from the eye trackers and will be reported in another publication.

Data Analysis

The methods of evaluating VOMS symptoms have been published extensively[10,26,28,29,32]; in this study, the total symptom provocation was calculated by summing the total number of increased symptoms from baseline (pre-test) for each VOMS item.[32] In addition, each VOMS subtest total reported symptoms were evaluated individually. All symptom data were taken

Figure 1. The VOMS prototype target stand comprises a mobile, 36-inch cross piece with white, 14-point targets at each end (A). This arm is adjustable to a horizontal or vertical position. An adjustable vertical arm (B) allows for adjustment to the height of the subject's nose. A measured distance of 36 inches is used to get the correct distance from the subject's nose to the target stand (C). There is also a sliding measure incorporating a 30-cm tape that extends to the subject's nose for NPC measurement (D). An additional sliding target (Figure 2) is used on the slide measure for the NPC test. NPC, near point of convergence; VOMS, vestibular/ocular motor screening.

Figure 2. The sliding target used to measure NPC for the VOMS prototype. The subject's nose is placed on the orange pad at the end of the slide measure. The subject then holds the sliding target. While focusing on the 14-point target, they move it toward their nose. At the point they see 2 targets, they are instructed to stop and the measurement is taken. This is repeated 3 times. A symptom assessment is taken after the third trial. NPC, near point of convergence; VOMS, vestibular/ocular motor screening.

verbally from the subject before each device administration, and after each VOMS subtest, whereas NPC was collected using the various measurement tools and further analyzed.

Statistical Analysis

Before any analyses, the data were examined for normalcy and influential skewness. All of the VOMS variables were not distributed normally; thus, nonparametric assessments were applied. The proportion of participant sex was examined by group and devices using chi-square analyses. A total of 30 Mann-Whitney *U* tests were conducted to compare baseline symptoms, change score, and each subtest total symptoms of the VOMS (smooth pursuits, H_Saccades, V_Saccades, NPC change, H_VOR, V_VOR, VMS, and NPC average) by device (MAN, PRO, VR). Furthermore, Mann-Whitney *U* tests were computed to examine sex differences to compare baseline symptoms, change score, and each subtest of the VOMS by device. Cohen's d effect sizes were calculated as small (d = 0.20-0.49), medium (d = 0.50-0.79), and large (d ≥ 0.80).[6,7] All tests were conducted using Statistical Package for the Social Sciences (SPSS, IBM Inc., 2020, Version 28.0.0.0). An alpha level of 0.05 was set a priori. No alpha level corrections were applied as all of the statistical analyses were planned.

RESULTS

Overall, there was no significant difference ($P > 0.05$) in the total proportion of male and female athletes who participated in the study by device (MAN: female athletes, N = 42.3%; male athletes, N = 57.7%; $P = 0.41$; PRO: female athletes, N = 42.2%; male athletes, N = 57.8%; $P = 0.41$; VR, female athletes, N = 36.8%; male athletes, N = 63.2%; $P = 0.25$) or within device.

Baseline and Symptoms Provocation

The results suggest that the MAN group (average, 0.446 ± 1.165) had significantly more symptoms than the PRO (average, 0.163 ± 0.644; $P < 0.01$; Cohen's d = 0.31) and the VR (average, 0.161 ± 0.933; $P < 0.01$; Cohen's d = 0.27) groups, with no significant difference between the PRO and VR ($P = 0.32$, Cohen's d = 0.01). Overall change score symptoms were significantly greater using the MAN (average, 0.396 ± 1.081) when compared with the PRO (average, 0.128 ± 0.427; $P < 0.01$, Cohen's d = 0.33) and the VR (average, 0.170 ± 0.903; $P < 0.01$; Cohen's d = 0.31), with a significantly greater change score symptoms between the PRO and VR ($P = 0.03$, Cohen's d = 0.03). This trend continued for each subtest of total symptoms except no significant differences were noted between the PRO and VR for any symptom provocation (Appendix Table A1, available in the online version of this article). The number of false positives for the overall change score (≥2 change score) and subtest total symptoms (≥2) were consistently highest in the MAN group (average, 7.6%; range, 4.5%-9%) with the lowest during PRO (average, 1.5%; range, 0.3%-1.9%) and VR in the middle of the devices (average, 2.9%; range, 1.4%-3.3%) (Appendix Table A2, available online).

Near Point of Convergence

The results of the NPC average measurement suggest that the VR produced (average, 2.99 ± 0.684 cm) significantly greater NPC distance than MAN (average, 2.91 ± 3.35 cm; $P < 0.01$; Cohen's d = 0.03) and PRO (average, 2.21 ± 1.81 cm; $P < 0.01$; Cohen's d = 0.57) conditions. MAN and PRO were not significantly different ($P = 0.98$; Cohen's d = 0.26). The number of false positives (>5 cm) were 20.7% during the MAN, 7.9% during PRO, and 0% during VR (see Appendix Table A2, available online).

Sex Differences

At baseline, female athletes reported similar symptoms to male athletes (female athletes, 0.35 ± 1.18; male athletes, 0.11 ± 0.51; $P < 0.21$) while using MAN. For PRO, female athletes reported significantly greater symptoms to male athletes (female athletes, 0.29 ± 0.87; male athletes, 0.06 ± 0.29; $P < 0.01$) and female athletes reported similar overall symptoms (female athletes, 0.34 ± 1.54; male athletes, 0.07 ± 0.49; $P = 0.66$) while using VOMS. This trend continued for the testing by sex for each device (Appendix Table A1, available online), whereas female athletes generally reported higher symptoms overall and significantly greater symptoms while using PRO. The number of false positives for the overall change score (≥2 change score) was similar during MAN when comparing sex (female athletes, 4.3%; male athletes, 4.7%), with the lowest during PRO (average, 1.5%; range, 0.3%-1.9%) and PRO (female athletes, 0.6%; male athletes, 1.9%) but it was higher in female athletes during the VOMS (female athletes, 5.1%; male athletes, 2.2%). When considering NPC measurement, false positives were high in both groups when comparing sex during MAN (female athletes, 19.1%; male athletes, 21.9%), moderately high during PRO (female athletes, 9.1%; male athletes, 7.1%) and no false positives were reported while using VR in each sex. The full summary data can be found in Appendix Table A1, available online.

DISCUSSION

This study aimed to examine the differences in VOMS when administered at baseline while using the traditional approach (MAN), a novel clinical prototype to standardize the location of the object of interest (PRO), or a VR system within a cohort of NCAA Division I athletes. A secondary aim was to examine sex differences within each testing modality. VOMS is designed to provoke symptoms and is assessed at baseline. The population is considered healthy in that they have not been diagnosed with a concussion and are not experiencing any concussion-specific symptoms at the time of assessment. The major findings of this research are (1) when using the MAN method, VOMS symptom provocation, subtest symptoms, NPC measurement, and overall false negatives are generally higher when compared with modalities that use standardized distances for objects of interest such as the PRO or VR; (2) providing the VOMS in VR does not significantly increase the overall symptoms reported when controlling for a history of motion sickness; (3) female athletes generally report higher VOMS symptom provocation, subtest symptoms, but not NPC measurements across all modalities. These findings are not surprising as standardizing the distance the eye travels during visual examinations can reduce overall eye strain and fatigue.[15,38,39] If not properly controlled, it can lead to false-positive symptoms. While most athletic facilities rely on trained raters and will not have access to VR systems, it is possible to create a measurement tool like the PRO (Figure 1) that can aid in standardizing VOMS. However, even when using an NPC measurement tool, false positives can exceed 7%.

Previous research has reported on baseline values using the VOMS in various populations[10,20,21,27,29,43]; however, to the authors' best knowledge, no current research has evaluated how VOMS symptoms are reported in VR. The data in the current study when using the MAN are comparable with other study means,[10,20,21] with a moderate increase in overall mean symptoms when compared with other NCAA Division I athletes.[10] For example, Eagle et al[10] reported an overall mean of 0.24 ± 0.64 symptoms during smooth pursuits and the current study observed 0.455 ± 1.17 symptoms. This general trend continued for all the VOMS subtests; however, the overall change score was higher in the literature (ie, 2.26 ± 4.73 vs 0.396 ± 1.081 symptoms).[10,21] It is possible that the higher VOMS scores while using the MAN method in the current study are due to the sample size (n = 111) as, generally, the more zero scores, which are more likely in larger samples, the more the means are reduced. This is a constant issue with VOMS as it is nonparametric due to the scale upon which it is rated (0-10). When considering the symptoms of the PRO or VR, these modalities closely matched previous literature,[21,29] and were smaller in overall baseline and subtest symptoms compared with other studies.[10] This is supported by the current study

given the significantly greater symptoms at baseline, change score, and on each subtest of VOMS. Both the PRO (n = 365) and VR (n = 212) methods of administering VOMS had higher sample sizes, which is comparable with previous literature and thus could explain the data discrepancy in the MAN modality by artificially deflating the mean with more zero symptom scores. Conversely, those who completed MAN had more symptoms at baseline, which could indicate that the population of NCAA athletes were reporting more symptoms at the time of testing in an attempt to skew the examination in the event of a concussion.[37] This could further explain the increased amount of symptoms throughout the VOMS while administered using the MAN. In a conflicting opinion, it is possible that the trained raters did not place their hands with the fixation objects at the appropriate lengths for smooth pursuit, H_Saccades, and V_Saccades, and did not control the distance the participant's head traveled during H_VOR and V_VOR. If the distance the eyes had to travel was larger than the recommended standards, it could produce eye strain and elicit more symptoms.[15,31,33,39]

The number of false negatives were generally highest on change score and subtest symptoms during MAN (4.5%-8.1%); however, those participants had more symptoms at baseline, which will inflate these numbers. PRO (0.3%-1.9%) reported the least amount of false negatives, while VR (1.3-3.3%) was lower MAN. A general trend occurred toward the end of the VOMS, where the number of false negatives increased. Whereas research indicates the administration of the VOMS does not influence subtest scores,[9] it is not impossible to rule out as symptom provocation is additive. The use of a change score for scoring could help to minimize the number of false negatives and excessive symptom reporting. Across the subtests, H_VOR (MAN = 8.1%, PRO = 1.6%, VR = 2.8%) and VMS (MAN = 8.1%, PRO = 1.9%, VR = 2.4%) had the highest amount of false negatives across all symptom reporting. The PRO and VR false negatives are lower than previous literature (Eagle et al[10]: range, 5.3%-9.0%) with the MAN being higher for smooth pursuits, H_Saccades, V_Saccades, NPC, and lower for H_VOR, V_VOR, and VMS. Our data suggest that the use of a standardized distance like the PRO or VR may reduce overall false negatives and enhance the accuracy of the examination at baseline. The use of the PRO enables the user to keep the target distance consistent from subject to subject. Consistent targets among subjects decrease the chance for false positives within the testing battery allowing the subject to use their eyes for foveal fixation. Similar to previous research,[10] the NPC measurement reported a high amount of false negatives (Eagle et al[10]: 15.9%; current study MAN = 20.7%, PRO = 7.9%, VR = 0%). During the standard administration, it is clear the false positives are very high and that these decrease drastically when using some type of convergence stick or measurement tool. The VR returned 0% false positives (>5 cm) during NPC and this is partially due to the VR system measuring the ocular midpoint within the HMD lenses rather than from the tip of the nose. Due to the immersive environment with the HMD sitting directly onto the eyes, it is not possible to measure from the tip of the nose and thus it is expected that the NPC measurement false negatives are not fully accurate. It is not recommended that providers mix and match the tools they use, but this may be limited to what is available during baseline testing.

When considering sex differences, female and male athletes reported similar change score symptoms, with female athletes reporting significantly more symptoms during the PRO than male athletes. During the VOMS subtests, female athletes consistently reported more symptoms across all modalities for smooth pursuits, H_Saccades, V_Saccades, H_VOR, and NPC, with significantly more symptoms during the PRO. However, on the H_VOR and VMS, female athletes reported significantly more symptoms during the PRO and VR. During NPC measurements, female athletes had significantly smaller measurements during the PRO but significantly less NPC on the VR. Lastly, female athletes tended to have higher false negatives across all modalities compared with male athletes, but this was not statistically analyzed. The overall differences in reporting by sex are not surprising as generally female athletes will report more symptoms after a concussion.[18,19,41] Clinically, these findings are important as female athletes may over-report at baseline or male athletes may under-report. This stresses the importance of using a change score when determining a concussion diagnosis while using the VOMS regardless of modality.

This research has significant limitations. First, the sample excluded any persons who had a previous concussion diagnosis and any history of motion sickness within the past 6 months. Evaluating a clean sample limits the ecological validity and generalizability of the population. Second, while the VOMS maintains sufficient psychometrics,[20,21,43] it is a subjective examination. The lack of objective data will continue to limit any/all symptom reporting at baselines and after a concussion. Athletes will continue to under-report or minimize symptom scores to their expected favorable outcome, which will influence results. Third, the use of the VR system is novel and the measurement of NPC within an HMD is different than when measured manually. Additionally, participants completed 1 of the 3 conditions (MAN, PRO, or VR) at baseline testing over the study period, rather than having each of the conditions administered in a counterbalanced manner.

CONCLUSION

The results of this study indicate that the administration of the VOMS with a VR platform may be a tool that can improve the collection of symptomology and NPC data without excessive symptom provocation. The asymptomatic VR testing is aimed at determining if VR would be a viable tool for assessment. The novel concept of using VR would require the development and distribution of the combination of software and hardware. Thus, it would take time to make this available to the majority of the practitioner population. Another solution would be to make this a phone app that goes with a simple, low-cost VR HMD. Advances in technology in this area will enable healthcare providers to share important diagnostic data in the assessment

and management of SRC. Additional research on the methods of secure data transfer among healthcare providers (ie, athletic trainers and sports medicine physicians) needs exploration for the implementation of the VR platform and VOMS administration. Its application to the symptomatic population is the next step in this ongoing study.

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