VALIDITY OF THE VESTIBULAR/OCULAR MOTOR SCREENING ASSESSMENT WITH REGARD TO ACUTE SUSPECTED CONCUSSION IN HIGH SCHOOL FOOTBALL

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

in

Sports Medicine

Department of Physical Therapy and Athletic Training

The University of Utah

May 2017

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

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ABSTRACT

Sideline concussion assessments can prove difficult in situations where athletes claim to be asymptomatic and do not present with obvious cognitive deficit. More thorough neurocognitive assessments, such as Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), can be difficult to administer on the sideline and are not always conclusive. The Vestibular/Ocular Motor Screen (VOMS) is designed to assess the vestibular and ocular symptomology of an individual suspected of suffering a concussion and has shown promising preliminary findings. This study sought to determine if the VOMS would correlate with current concussion assessment methods in acute settings.

Participants were recruited from local high schools and included football athletes who sustained a suspected concussion. Athletes suspected of a concussion were administered a subsection of the VOMS before other concussion assessment methods. Results were compared to the Standardized Concussion Assessment Tool (SCAT 3) and ImPACT tests to determine the ability of the VOMS to assess the presence of concussion in acute situations. It was hypothesized the VOMS would correlate with concussion evaluations and lend more support to the diagnosis. Receiver Operating Curve (ROC) analysis and Phi correlations were conducted.

The study concluded with a sample of 11 athletes evaluated for suspected concussion with five concussions diagnosed through assessments other than the VOMS. Our study findings revealed that relationship and diagnostic ability were evident

regarding specific symptoms within individual tests, which comprises the VOMS. However, the subset of the VOMS utilized for this test did not prove to be a viable test metric to determine the presence of an acute concussion. Interestingly, significant relationships and diagnostic capability were identified within this tested subset of the VOMS, specifically regarding concussion suspicion when fogginess and dizziness are present.

Further research is warranted to determine if these findings can be used in a diagnostic capacity, though at minimum, our study findings provide a basis for increased clinical suspicion of concussion when these symptoms are present.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Charlie Hicks-Little, Dr. Jessica Tidswell, and Dr. Ryan Burns for the work they have contributed toward the completion of this study and manuscript. This would never have been completed without the guidance of Dr. Hicks-Little, and I would not have succeeded further without the guidance of Dr. Tidswell.

I would also like to thank my mother Robin and sister Emilee for their continuous love and support, without which I would be aimless.

Lastly, I would like to thank my friends and colleagues Jenny, Julia, Travis, and Hannah, without whom my motivation and data would have greatly suffered.

INTRODUCTION

Concussions has been referred to as a “silent epidemic” (Guskiwicz, 2017). To begin looking at concussions, we first need to define them: “Concussion may be caused by a direct blow to the head or elsewhere on the body from an ‘impulsive’ force transmitted to the head…and may cause a gradient of clinical syndromes that may or may not involve a loss of consciousness. Resolution of clinical and cognitive symptoms typically follows a sequential course” (Guskiewicz et al., 2004). Certainly, there has been an increased awareness regarding the injury; so much so, in fact, that youth participation in youth football has dropped 27.7% (Moore, 2016). There are 3.8 million concussions every year from sports (Guskiewicz et al., 2004). Concussions account for 56% of all emergency department visits for ages 8-13 (Guskiewicz et al., 2004), and 46% of all concussions for ages 14-19 are sports related (Guskiewicz et al., 2004). As awareness of concussions has grown, new methods for testing have been developed. Simple sideline questioning has evolved to multi-index, paper, and computer-based neurocognitive testing batteries as well as various symptom scales to determine the presence or absence of concussion (Galetta, Brandes, Maki, Dziemianozicz, & Laudano, 2011; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006). An advantage of neurocognitive testing is the ability to take preseason baselines; these baselines can be compared with postinjury assessments in order to determine if a concussion is present, help inform return to play procedures, and ultimately a decision regarding return to activity (Silver, 2012).

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is the most commonly utilized assessment tool, but each year, more testing batteries are developed. The military has developed their own version; the Automated Neuropsychological Assessment Metrics (ANAM). Like ImPACT, ANAM consists of a series of subtests which evaluate tasks such as processing speed, short-term memory, working memory, and resistance to interference (Brown, Guskiewicz, & Bleiberg, 2007). The Sport Concussion Assessment Tool 3 (SCAT 3) is a paper battery that combines a symptom scale with balance assessment; and assesses immediate memory, orientation, coordination, concentration, and delayed recall space (Jinguji et al., 2012; Silver, 2012).

Not all testing batteries include a symptoms scale; therefore, athletic trainers may choose to add one to their evaluations. Examples of these are the Post-concussion Symptom Scale (PCSS) and the British Columbia Cognitive Complaints Inventory (BC-CCI). PCSS is a 22-item measure that assesses the presence and severity of post-concussion symptoms on a 7-point Likert scale. This test is also included as a part of ImPACT (Norrie et al., 2010). BC-CCI is a 6-symptom scale that measures perceived cognitive problems on a scale from 0-3. The Test of Memory Malingering (TOMM) employs a forced recognition paradigm using 50 black and white line drawings. Two trials are executed 20 minutes apart and if the patient receives a score of 45 or lower on the second trial, it is indicative of underperforming (Van Kampen et al., 2006).

Randolph et al. (2005) conducted a literature review in order to determine the usefulness of neuropsychological testing in the management of sport concussion. They assessed the reliability, sensitivity, validity, change score, and clinical utility of standard paper and pencil tests, ANAM, CogSport, HeadMinder: Concussion Resolution Index (CRI), and ImPACT. They concluded none of the tests met the necessary criteria to support a clinical application for management of concussion, yet many of these tests have become widely used. This review was published in 2005; since then, many advances and newer versions of each test have been created (Kontos, Sufrinko, Elbin, Puskar, & Collins, 2016). Although clinicians are learning more about concussions and tests are being improved, athletes may still find ways to stay in the game, especially when our current sideline tests may not be sensitive enough to accurately determine when a concussion is present.

Concussion education for athletes, parents, and coaches is more widespread, including legislation in a number of states to ensure the safety of athletes. However, there are athletes who, when having sustained a concussive blow and present without outward deficit, will lie and attempt to deceive clinicians in order to continue participation (Silver, 2012). In situations like these, objective measures can prove very useful to the clinician.

Assessments using the aforementioned tests rely on the athlete being honest with their practitioner. Self-Reported Symptom Scales (SRSS) are an integral part of most concussion screenings and is a tool commonly used by clinicians regardless of setting (sideline or in-clinic). Because of the varying and unique ways that athletes present on the sideline post suspected concussion, neurocognitive assessment can sometimes prove inconclusive. The Vestibular Ocular Motor Scale (VOMS) assesses different neurological systems from most other sideline concussion assessments, such as the SCAT 3. The VOMS also contains an objective measure: the Near Point Convergence component. This provides information the athlete does not volunteer, which can prove to be useful as many athletes can present without any outward neurologic symptomology, and state minimal, if any subjective deficits, thereby providing the clinician with little to no objective data with which they can make their diagnosis (Kelts, 2010; Pearce et al., 2015).

The Vestibular Ocular Motor Scale is a tool specifically designed to assess and determine the presence of dysfunction in the vestibular and ocular systems through the use of succinct, brief individual tests, which, when used in conjunction, provide a very sensitive test measure (Mucha et al., 2014). The test was developed at the University of Pittsburgh by a team of physicians, physical therapists, and athletic trainers. There are other tests that focus on the ocular system, specifically the King-Devick Test. The King-Devick Test uses letters spaced at uneven intervals to assess concentration, verbal acuity, and eye movement. Therefore, the King-Devick Test can assess saccadic eye movement like the VOMS (Galetta, 2011). However, current VOMS research shows the most sensitive combination of vestibular and ocular tests does not involve testing saccadic eye movement, though it can be a good initial indicator of dysfunction (Mucha et al., 2014). There are deficiencies in current VOMS literature, however; the VOMS has been validated in a concussion clinic in a subacute timeframe: evaluations took place 5.5 +/- 4 days following a concussive impact (Mucha et al., 2014). In previous research, the VOMS was not administered in a uniform order (Mucha et al., 2014). These limitations preclude the VOMS involvement in acute concussive injuries in settings where the patient could be less inclined to be forthcoming with the clinician regarding their injury. Our study seeks to close this gap in the literature by examining the VOMS in an acute setting.

The purpose of this study was to determine if administering the VOMS on the sideline in conjunction with an SRSS or an assessment method that uses an SRSS (such as the SCAT 3) will yield measurable, predictable results on the validity of the VOMS. Through the use of a prospective observational study design, we hoped to determine if the VOMS could predict the presence of concussion symptoms in an acute, sideline setting. We hypothesized the VOMS would correlate with concussion evaluations and lend more support to sideline diagnoses of acute concussions.

MATERIALS AND METHODS

Research Design

A prospective, observational study was utilized. The dependent variable was reliability of VOMS to determine the presence of symptomology present in high school football players suspected of a concussion. The independent variable was the onset of symptomology occurring due to concussion.

Participants

Participants were recruited from three local high schools through the University of Utah Healthcare Athletic Training Outreach Program. All high school football players that sustained a concussion mechanism throughout preseason, the regular season, and the postseason took part in completing the VOMS on the sideline. Athletes were disqualified if they had any type of psychological disorder (depression, anxiety, etc.), a history of three or more concussions, a history of a concussion within the last 6 months, or if emergency procedures took precedence over test administration. Basic demographic information such as age and sex was collected with the consent of both the parents and athlete.

Procedure

Parents/Guardians and athletes were provided the consent cover letter, having obtained a waiver of documentation of consent from the University of Utah Institutional

Review Board. Athletes underwent their normal preparticipation screening (pre-participation evaluation, physical, ImPACT baseline testing), normal concussion assessment (sideline screening tools such as SCAT 3, BESS) and a normal progression for return to play (RTP) in accordance with Utah legislation, Utah High School Athletic Association (UHSAA), University of Utah Healthcare Concussion guidelines, and protocols according to specific district and school policies. Participating high schools each determined a minimum standard of testing protocol for return to sport. The only modification to this process was the sideline implementation of the VOMS prior to normal sideline concussion assessment. The specific components of the VOMS that were administered was the Near Point Convergence, Vestibular Ocular Reflex, and Visual Motion Sensitivity tests. The Range of Motion for the Vestibular Ocular Reflex was not restricted to 20° during this study. The administration of this test took approximately 5-7 minutes and 1-2 minutes to score (scoring was not completed on the sideline). The VOMS was conducted once per suspected concussion instance, thereby not influencing the decision-making process, as the measurement tool was being assessed separately from current testing methods. Scores were totaled after the decision regarding the athlete's concussion had already been determined.

<u>Instrumentation</u>

The Vestibular/Ocular Motor Screening (VOMS) Assessment is a provocation test designed to determine dysfunction in the vestibular or ocular system in a patient through a pretest, intervention, posttest model where the test is the patient-reported symptomology. While a complete VOMS assessment uses five specific tests (1) smooth pursuit, (2) horizontal and vertical saccades, (3) near point convergence, (4) horizontal vestibular ocular reflex (VOR), and (5) visual motion sensitivity (VMS), Mucha et al. reported the highest diagnostic ability of the test to be a combination of the (1) near point convergence, (2) horizontal vestibular ocular reflex (VOR-h), and (3) visual motion sensitivity test (VMS). Mucha et al. also reported the use of the vertical vestibular ocular reflex (VOR-v) needed to be assessed (Mucha et al., 2014).

As such, we utilized a subset of the VOMS compromised of (1) near point convergence (CON), (2) horizontal vestibular ocular reflex (VOR-h), (3) vertical vestibular ocular reflex (VOR-v), and (4) visual motion sensitivity test (VMS).

The VOMS is graded by the patient with a scale of 0-10 both prior to and after each specific test. An increase of 2 or more on this symptom scale is considered a positive indication of dysfunction. All specific tests function with this methodology with the exception of the near point convergence test. The result of the near point convergence test is the average of three trials. If that average is determined to be equal or greater than 6cm, then it is considered a positive test. This procedure is explained thoroughly in the Appendix.

Potential Difficulties

Clinicians participating in the study were educated in the usage of the VOMS, and, more specifically, not to use it as an assessment method during the study to ensure proper separation of the intervention.

A potential complication was the extra time that this test would generate in assessment time during sideline evaluations. This becomes an issue in sideline testing because of an athlete's removal from play; the athlete may be a critical component of the team or may be integral to the team's strategy. To counter this, coaching staff received foreknowledge and education about the potential benefits of this study. The test took approximately 5 minutes to administer on the sideline with 1-2 minutes needed to score it. However, because of the environment in which we utilized this test, scoring did not occur until after the full sideline assessment had taken place.

Statistical Analysis

The data were normalized to prevent skewness from outliers. Phi correlation coefficients were used to analyze the significance of the relationship between the onset of symptoms and the ability of the VOMS subset to determine the presence of a concussion. Receiver operating curve (ROC curve) analysis was then utilized to determine the diagnostic ability of the VOMS while sensitivity and specificity were calculated to determine the individual and group metrics for the VOMS. Statistical significance of the ROC curves was analyzed using the area under the curve (AUC) scores with 95% Confidence Intervals. An a priori alpha level was set at $p \leq 0.05$ and all analyes were carried out using SPSS v21.0 statistical software package (Armonk, NY, USA).

RESULTS

The change in symptom scores assessed through the VOMS were given abbreviated data values. For example, change scores are all indicated by _ch, while each symptom is represented by the first three letters, respectively (Fogginess- FOG, Dizziness-DIZ, Nauseous-NEA), or abbreviated with the first letters (Head Ache- HA). Each test is abbreviated as indicated in the instrumentation subsection of the Materials and Methods section.

Demographic Data

The study concluded with a sample of 11 athletes having been evaluated with five concussions diagnosed though assessments other than the VOMS assessment. All athletes assessed were high school aged males (mean age: 16.5 +/- 1.2) football players. Of those assessed, all met the study inclusion criteria; therefore, all athletes were assessed on the sideline immediately following a suspected concussion incidence observed by the onsite medical professional. All other descriptive statistics are illustrated in Table 1.

Correlations

A Phi coefficient was used to determine the correlation between change scores for symptoms within each test to the presence of a concussion. There was a moderate and positive correlation between VOR-h_FOG_ch scores and a diagnosis of concussion (phi

= .59, *p* = .05). There was also a moderate and positive correlation between VMS_FOG_ch scores and a diagnosis of a concussion (phi = .69, *p* = .01). There was a weak positive correlation between VOR-h_DIZ-ch scores and the diagnosis of a concussion (phi = .49, *p* = .12) while there was also a weak positive correlation between VOR-v_FOG_ch scores and the diagnosis of a concussion (phi = .49, *p* = .12). Table 2 expresses these data.

ROC Curve Analysis

The diagnostic ability of the VOMS was assessed through the usage of a ROC curve analysis. Figure 1 shows an ROC curve analysis with more general subset results, while a more in-depth breakdown of specific symptoms diagnostic capability is displayed in Figure 2. Tables reflecting these data are also represented (Table 3 and Table 4). The significant data points come from the specific ROC curve (Figure 2 and Table 4): VOR-h_FOG_ch: AUC = .8, 95%CI (.53, 1) and VMS_FOG_ch: AUC = .87, 95%CI (.642, 1). There are also two data points that are trending towards significance: VOR-h_DIZ_ch: AUC = .73, 95%CI (.43, 1) and VOR-v_FOG_ch: AUC = .73, 95%CI (.43, 1).

Sensitivity and Specificity

Sensitivity and specificity both directly relate to the reliability of the test to correctly diagnose the presence or absence of a condition, whereas sensitivity relates to the tests ability to correctly identify a true positive and specificity relates to the tests ability to identify a true negative. The only specific measures in this VOMS subset that showed significant diagnostic usage, as outlined in Table 4, were the VOR-h and the

VOR-v. The VOR-h had a sensitivity of 60%, specificity of 86%, but a positive and negative predictive value of 75%. The VOR-v had a sensitivity of 60%, specificity of 100%, and a positive predictive value of 100% and a negative predictive value of 60%.

Table 1. Descriptive statistics

	Mean	Standard Error	Standard Deviation	Lower Range	Upper Range
VOR-h	.55	.81	2.7	-3	7
VOR-v	.27	1.17	3.9	-6	10
VMS	1.36	1.32	4.4	-4	12
Concussion	.45	1.57	.52	X	X

VOR-h: Horizontal Vestibular Ocular Reflex; VOR-v: Vertical Vestibular Ocular Reflex; VMS: Visual Motion Sensitivity

Table 2. Symptoms correlated with presence of a concussion

	Phi coefficient	*p*-value
VOR-h_FOG_ch	.59	.05*
VMS_FOG_ch	.69	.01*
VOR-h_DIZ_ch	.49	.12
VOR-v_DIZ_ch	.49	.12

1. $p \leq .05$ 2. VOR-h_FOG_ch: change score for fogginess within the Horizontal Vestibular Ocular Reflex; VMS_FOG_ch: change score for fogginess within the Visual Motion Sensitivity; VOR-h_DIZ_ch: change score for dizziness within the Horizontal Vestibular Ocular Reflex; VOR-v_DIZ_ch: change score for dizziness within the Vertical Vestibular Ocular Reflex

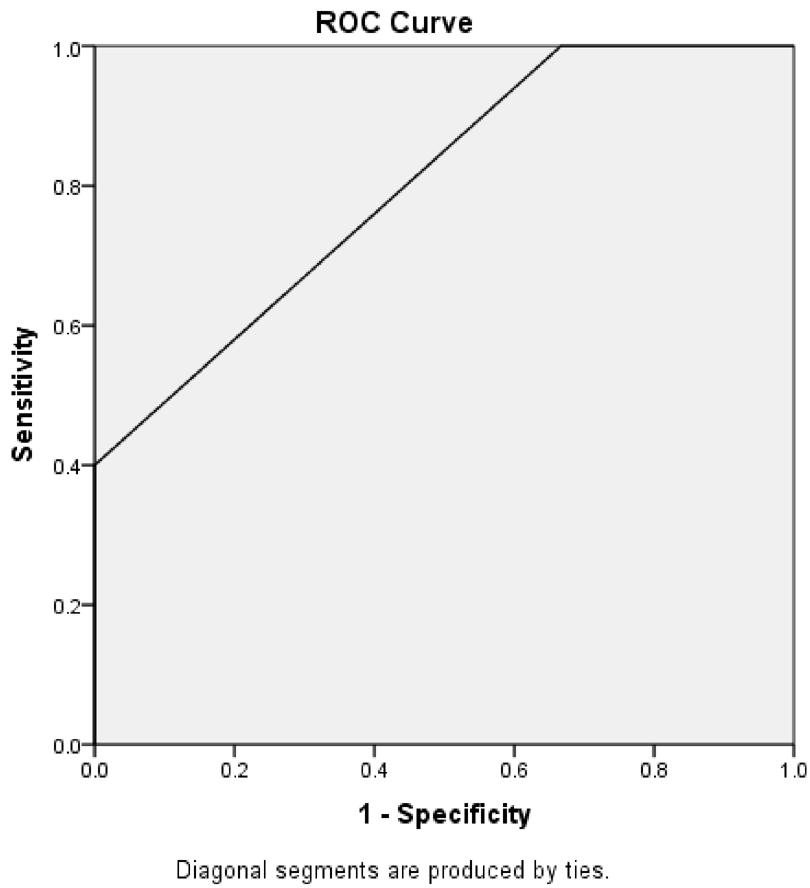

Figure 1. ROC curve for VORh_Fog_ch AUC = .80 (53, 1.00)

Table 3. ROC curve data for individual tests

Test Variable	Area Under Curve (AUC)	95% CI Lower Bound	95% CI Upper Bound
VOR-h_ch	.75	.43	1.00
VOR-v_ch	.52	.15	.89
VMS_ch	.65	.29	1.00
Conv_1	.58	.21	.99
Conv_2	.52	.13	.90
Conv_3	.55	.18	.93

VOR-h_ch: change score for Horizontal Vestibular Ocular Reflex; VOR-v_ch: change score for vertical Vestibular Ocular Reflex; VMS_ch: change score for Visual Motion Sensitivity; Conv_: Near Point Convergence

Table 4. ROC curve data for individual symptoms within each test

Test Variable	Area Under Curve (AUC)	95% CI Lower Bound	95% CI Upper Bound
VOR-h_HA_ch	.57	.19	.95
VOR-h_DIZ_ch	.73	.43	1.00
VOR-h_NEA_ch	.60	.25	.96
VOR-h_FOG_ch	.80*	.53	1.00
VOR-v_HA_ch	.57	.19	.95
VOR-v_DIZ_ch	.55	.18	.92
VOR-v_NEA_ch	.50	.12	.88
VOR-v_FOG_ch	.73	.43	1.00
VMS_HA_ch	.53	.16	.91
VMS_DIZ_ch	.55	.16	.94
VMS_NEA_ch	.45	.08	.82
VMS_FOG_ch	.87*	.64	1.00
Conv_1	.58	.21	.96
Conv_2	.52	.13	.90
Conv_3	.55	.18	.93

VOR-h: Horizontal Vestibular Ocular Reflex; VOR-v: Vertical Vestibular Ocular Reflex; VMS: Visual Motion Sensitivity; Conv: Near Point Conversion; HA: Headache; DIZ: Dizziness; NEA: Nausea; FOG: Fogginess; ch: Change score.

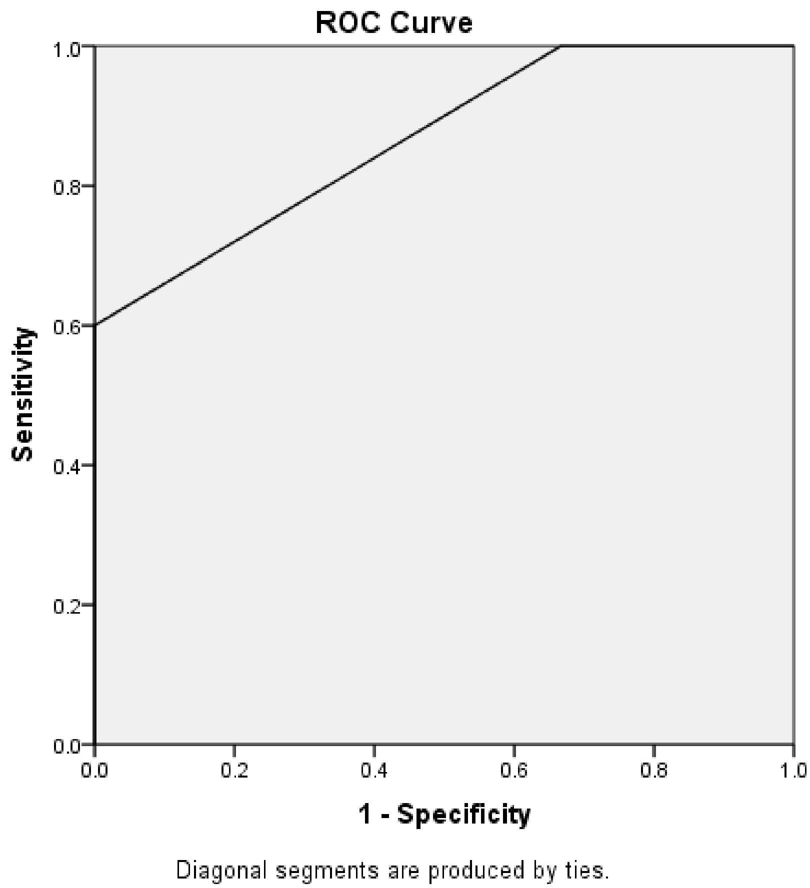

Figure 2. ROC curve for VMS_Fog_ch AUC = .867(.64, 1.00)

Table 5. Sensitivity and specificity of VOMS subset

	VOR-h	VOR-v	VMS	Conv.
Sensitivity	60%	60%	60%	40%
Specificity	86%	100%	60%	50%

DISCUSSION

There are 3.8 million sport-related concussions annually that account for 8.9% of all high school injuries (Guskiewicz et al., 2004). Of all high-school-aged concussions (14-19), 46% are sport related (Guskiewicz et al., 2004). These statistics indicate a need for a gold standard diagnostic test for concussion that does not exist. The purpose of this study was to determine the acute diagnostic ability of the VOMS to determine the presence or absence of a concussion in a juvenile population, and to determine if this assessment would correlate with current acute assessment methods. This study, although only including a small sample size, did reveal significant results in two categories through correlation and ROC curve testing. The change scores in the Visual Motion Sensitivity test (VMS) when athletes were asked to grade the changes in their fogginess showed significant changes consistent with the diagnosis of a concussion (p = .01, AUC = .87). Also, the change scores in the Horizontal Vestibular Ocular Reflex were significant, again with fogginess (p = .05, AUC = .8). In two separate tests, fogginess change scores were shown to be a significant indicator of a concussion and were also shown to have good diagnostic ability. Kontos et al. describe a global symptom cluster observed through their research, which is consistent with clinician observations post concussive injury. Termed the cognitive-migraine-fatigue factor, these symptoms include fogginess, dizziness, difficulty concentrating, drowsiness, and feeling slowed down. Among those is not the most commonly reported symptom: headache. The cognitive-migraine-fatigue factor accounts for 49% of postconcussive symptoms. Kontos goes onto describe how the cognitive-migraine-fatigue loading factor may “reflect a global concussion factor.” Given this study’s findings in conjunction with Kontos et al. we can begin to establish how fogginess should be a symptom clinician regard with high suspicion.

Additionally, it must be noted that one further change score indicated a trend towards significance both in correlation and in diagnostic capability: the change score in dizziness for the Horizontal Vestibular Ocular Reflex (p = .12, AUC = .73). There were two other change scores that indicated a trend towards significance in one of the two tested areas: The Vertical Vestibular Ocular Reflex showed a trend towards significance, correlating well with the presence of a concussion while assessing dizziness (p = .12); while that same test, VOR-v showed a trend towards significance while assessing fogginess in its diagnostic ability (AUC = .73). The VOR-h and VOR-v showed a moderate relationship as well as moderate diagnostic ability regarding dizziness and fogginess despite low power throughout this study. Fogginess, as discussed above, has been shown to correlate with the presence of a concussion across current research (Kontos et al., 2012). Dizziness is also among those symptoms listed among the cognitive-migraine-fatigue symptom loading list (Kontos et al., 2012). These two symptoms along with headache and nausea are reflected in the VOMS assessment (Mucha et al., 2014). While needing more research to substantiate its relationship and its diagnostic ability regarding concussion, dizziness shows promise to determine the presence of a concussion.

While each test did not meet significance for diagnostic ability, both the Horizontal Vestibular Occular Reflex (AUC = .75 (.43, 1.00)) and Visual Motion

Sensitivity (AUC = .65 (.29, 1.00) tests showed moderate AUC, indicating possible significance in future studies.

Clinical Implications

Current diagnostic assessment relies on many different assessment tools (Galetta et al., 2011; Randolph et al., 2005; Silver, 2012) and the expertise of the clinician. There is no gold standard tool for diagnosing a concussion. Mucha et al. proposed the VOMS as a diagnostic tool with very good diagnostic ability (AUC = .89). The subset of the VOMS that produced that high diagnostic ability was the VOR-h, VMS, and Conv. scores. We utilized that subset to validate those diagnostic findings in an acute setting. To standardize our assessment, we conducted every trial in a consistent order (refer to Appendix).

The results of this study indicate that while power may not have been sufficient to reproduce the results of Mucha et al., they were significant enough to identify specific markers within the VOMS that clinicians can utilize in their diagnosis. Fogginess in particular showed significant results across two specific diagnostic tests within the VOMS, while also trending towards significance in one other test. Dizziness showed promising results, nearing significance. These findings indicate that the usage of the VMS, VOR-h, and VOR-v can indicate the presence of concussion when used specifically regarding the symptoms of fogginess and dizziness.

Limitations

The original research detailing the VOMS by Mucha et al. was able to effectively show that the VOMS subset utilized in this study was able to diagnose the presence of a concussion with an area under curve (AUC) of .89% (Mucha et al., 2014). This means that they were able to determine dysfunction correctly 89% of the times from the VOMS alone. This study was unable to reproduce those same results, the most likely reason being that this study was not able to obtain a similar number of participants. Mucha et al. were able to test 64 concussed individuals, while this study was only able to obtain 11 participants. This was likely due to Mucha et al. utilizing an outpatient concussion clinic while this study was conducted in an acute sideline manner at three local high schools.

Another limiting factor was multiple collectors. These collectors were trained in the usage of the VOMS and correct data collection techniques. However, intertester reliability was not assessed in this study.

Lastly, there was no guarantee each high school that participated in the study would have evaluated a concussion the same way on the sideline. Most typically, SCAT 3 (including a PCSS), cranial nerve assessment, and upper and lower quarter screens are utilized, but other metrics may be used such as the King-Devick test. It should be noted that the King-Devick test is less likely to be used due to cost and time effectiveness at a secondary institution. A survey of participating medical professionals was not conducted prior to the study. This was due in part to ease the constraints this study put on practitioners in stressful, time-sensitive situations.

Future Research

The results of this study and the results of Mucha et al. warrant further research into the validity of the VOMS as a sideline assessment. Among healthcare professionals, it is already in wide use in acute and subacute situations. While Mucha et al. were able to validate its clinical usefulness in a subacute setting, it continues to be unvalidated in an acute evaluative setting. This study provides some insight into possible markers for which to watch, but does not provide enough evidence to validate its use.

Generally speaking, this metric has been validated for use within an adolescent population (Mucha et al., 2014), but it relates specifically to a subacute situation. Other areas for growth would be chronic phases of concussion as well as with other athletic populations. There has yet to be research conducted across different sports: How does sport culture effect the responses of athletes and therefore the results of this test metric? Collegiate athletes have been assessed with the VOMS with positive findings (Kontos et. al., 2016). However, there is still a gap in the research regarding acute concussion situations. Differences in collegiate level could also prove to be an interesting area of research: How does athletic scholarship and the pressure of competition figure into testing? Gender and age differences may also play a role in its diagnostic ability (Frommer et al., 2011). There is also the potential for regional differences in the way that concussion evaluations are conducted in an acute situation. This could stem from academic differences in undergraduate athletic training programs or what that specific clinician is trained to do. The VOMS use in an acute juvenile population remains to be validated. Lastly, further research into what each subtest can indicate in relation to rehabilitation is also warranted.

Conclusion

The current findings indicate that there is no group of subtests or any individual test of the VOMS that can accurately determine the presence of a concussion in an acute situation with adolescent athletes. However, the number of participants does not allow us to state definitively that the VOMS, with an individual test or a subset group of tests, cannot determine the presence of a concussion. The VMS and VOR-h, in regards to fogginess, both produced significant diagnostic ability for concussion. These findings, despite low power, indicate that these tests could be validated for acute assessment with further research. Both VOR-h and VOR-v showed results for dizziness that are nearing significance, again, indicating the potential for these test to be validated in future findings.

Interestingly, in current research, dizziness and fogginess are symptoms among a "Cognitive-Migraine-Fatigue" factor (Kontos et al., 2012). These symptoms have been shown to be among those present that incur significance on SRSS postconcussion compared to presence on baseline testing. These symptoms: fogginess, dizziness, difficulty concentrating, drowsiness, and feeling slowed down, have been shown to be more present after a concussion than at baseline (Kontos et al., 2012).

APPENDIX

Name of Athlete: School:	Headache 0-10	Dizziness 0-10	Nausea 0-10	Fogginess 0-10	Comments
Baseline Sx					
Convergence					**Near Point (in cm)** Trial 1: Trial 2: Trial 3:
VOR-Horizontal					
VOR- Vertical					
Visual Motion Sensitivity Test					

Convergence – Measure the ability to view a near target without double vision. The patient is seated and wearing corrective lenses (if needed). The examiner is seated front of the patient and observes their eye movement during this test. The patient focuses on their thumb nail at arm's length and slowly brings it toward the tip of their nose. The patient is instructed to stop moving the target when they see two distinct images or when the examiner observes an outward deviation of one eye. Blurring of the image is ignored. The distance in cm. between target and the tip of nose is measured and recorded. This is repeated a total of 3 times with measures recorded each time. Record:
Headache, Dizziness, Nausea & Fogginess ratings after the test.

Vestibular-Ocular Reflex (VOR) Test – Assess the ability to stabilize vision as the head moves. The patient and the examiner are seated. The patient hold their arm in front of them with their focus on their upright thumb (thumbs up position).

> **Horizontal VOR Test**: The patient is asked to rotate their head horizontally while maintaining focus on the target. The head is moved at an amplitude of 20 degrees to each side and a metronome is used to ensure the speed of rotation is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves back and forth to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Fogginess ratings 10 sec after the test is completed.

> **Vertical VOR Test**: The test is repeated with the patient moving their head vertically. The head is moved in an amplitude of 20 degrees up and 20 degrees down and a metronome is used to ensure the speed of movement is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves up and down to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Fogginess ratings after the

test.

Visual Motion Sensitivity (VMS) Test – Test visual motion sensitivity and the ability to inhibit vestibular-induced eye movements using vision. The patient stands with feet shoulder width apart, facing the field. The examiner stands next to and slightly behind the patient, so that the patient is guarded but the movement can be performed freely. The patient holds arm outstretched and focuses on their thumb. Maintaining focus on their thumb, the patient rotates, together as a unit, their head, eyes and trunk at an amplitude of 80 degrees to the right and 80 degrees to the left. A metronome is used to ensure the speed of rotation is maintained at 50 beats/min (one beat in each direction). One repetition is complete when the trunk rotates back and forth to the starting position, and 5 repetitions are performed. Record: Headache, Dizziness, Nausea & Fogginess ratings after the test.

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