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Lucy Parrington

Laurie A. King

Carrie W. Hoppes

Maxwell J. Klaiman

Patrick Michielutti

See next page for additional authors

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Exploring Vestibular Ocular Motor Screening in Adults With Persistent Complaints After Mild Traumatic Brain Injury

Lucy Parrington, PhD; Laurie A. King, PhD; Carrie W. Hoppes, PhD; Maxwell J. Klaiman, BA; Patrick Michielutti, DPT; Peter C. Fino, PhD; Leland E. Dibble, PhD; Mark E. Lester, PhD; Margaret M. Weightman, PhD

Objective: The purpose of this study was to (1) explore differences in vestibular ocular motor screening (VOMS) symptoms between healthy adults and adults with persistent symptoms after mild traumatic brain injury (mTBI), and (2) explore the relationships between VOMS symptoms and other measures (self-reported vestibular symptoms, clinical measures of balance and gait, and higher-level motor ability tasks). **Setting:** Research laboratory setting. **Participants:** Fifty-three persons with persistent symptoms (>3 weeks) following mTBI and 57 healthy controls were recruited. Eligibility for participation included being 18 to 50 years of age and free of medical conditions that may affect balance, with the exception of recent mTBI for the mTBI group. **Design:** Cross-sectional. **Main Measures:** The primary outcomes were the VOMS symptom scores and near point of convergence (NPC) distance. Secondary outcomes included the Dizziness Handicap Inventory (DHI) total and subdomain scores, sway area, Functional Gait Analysis total score, gait speed, and modified Illinois Agility Task completion time, and Revised High-Level Mobility Assessment Tool total score. **Results:** The mTBI group reported more VOMS symptoms (z range, −7.28 to −7.89) and a further NPC ($t = -4.16$) than healthy controls (all Ps < .001). DHI self-reported symptoms (total and all subdomain scores) were strongly associated with the VOMS symptom scores (rho range, 0.53-0.68; all Ps < .001). No significant relationships existed between VOMS symptoms and other measures. **Conclusion:** Significant group differences support the relevance of the VOMS for mTBI in an age-diverse sample with persistent symptoms. Furthermore, strong association with DHI symptoms supports the ability of the VOMS to capture vestibular complaints in this population. **Key words:** *concussion*, *mTBI*, *oculomotor*, *vestibular*, *VOMS*

Author Affiliations: *Department of Dietetics, Human Nutrition and Sport, La Trobe University, Victoria, Australia (Dr Parrington); Department of Neurology, Oregon Health & Science University, Portland (Drs Parrington and King); Army-Baylor University Doctoral Program in Physical Therapy, Fort Sam Houston, Texas (Drs Hoppes and Lester); Courage Kenny Research Center, Allina Health, Minneapolis, Minnesota (Mr Klaiman and Drs Michielutti and Weightman); Departments of Health and Kinesiology (Dr Fino) and Physical Therapy & Athletic Training (Dr Dibble), University of Utah, Salt Lake City; Department of Physical Therapy, Texas State University, Round Rock (Dr Lester).*

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Corresponding Author: *Department of Dietetics, Human Nutrition and Sport, La Trobe University, Plenty Rd & Kingsbury Dr, Bundoora VIC 3086, Australia (l.parrington@latrobe.edu.au).*

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EVALUATING VESTIBULAR and ocular motor systems is an important part of a comprehensive clinical assessment for mild traumatic brain injury (mTBI; eg, sports-related concussion). There is growing support of the vestibular ocular motor screening (VOMS).[1,2] However, the majority of research supporting the VOMS has been conducted with acutely concussed adolescent and high school athlete populations.[1–7] Moreover, data supporting the use of the VOMS in older, nonathletic populations are scarce, and psychometric properties on the VOMS in this population are limited.

Although initially developed as a screening tool for the purpose of distinguishing between concussed and healthy adolescents,[1–7] there has been growing interest from clinical and research teams to use this tool outside the scope of screening and with different populations[8] (eg, addition of VOMS to Military Acute Concussion Evaluation 2 [MACE2][9]). Such examples include use in subacute and persistent time frames,[8,10–15] use with adults,[8,15,16] and also for tracking recovery.[8,16–18] Given changes that may occur throughout recovery (eg, expected improvements in some or all symptoms between 2 and 4 weeks),[19] and known differences in the vestibular and oculomotor systems that occur with aging,[20,21] findings from research conducted in younger and athletic populations may not be generalizable to adults following mTBI, especially those with symptoms that persist beyond expected recovery timelines. Thus, further evidence is needed to support VOMS use outside its original scope including clinical use for nonathlete adults with concussion symptoms that persist beyond 3 weeks.

In populations with mTBI and persistent dizziness and imbalance following injury, and in whom sensory dysfunctions are common, the VOMS may be useful to help screen for vestibular and oculomotor deficits for the purpose of aiding clinical subtyping, for prescribing rehabilitation, and for provoking symptoms in individuals who are not forthcoming with their recovery status. However, we currently lack studies to support using the VOMS in this context and thus exploring how adults with persistent mTBI respond to VOMS tests provides an important first step for implementation. Furthermore, determining how the VOMS relates to real-world function and patients' perceived disability may provide additional evidence for the use of the VOMS outside its original scope. For example, associations between scales such as the Dizziness Handicap Inventory (DHI) that measure the impact of dizziness and the VOMS would strengthen the validity of the VOMS to capture vestibular dysfunction.

It is also plausible that the deficits captured through the VOMS assessment would relate to many levels of balance control, thereby expanding the interpretability and validity of this assessment tool. For example, it is plausible that symptom exacerbations identified by the VOMS would be associated with deficits in quiet stance, due to the role of the vestibular system in balance control.[22] Namely, there is increased reliance on the vestibular system in the absence of vision,[22] and when balancing on unstable surfaces (ie, foam pad), where somatosensory information is less reliable.[22] Deficits measured by the VOMS may also relate to more dynamic function, such as walking and turning, due to the roles of the vestibulospinal tract in mediating locomotion,[23] and the role of vision in the control of gait.[24] Furthermore, complex gait tasks (eg, walking with yaw or pitch plane head rotations) can be more provocative for individuals with vestibular complaints[25,26] and thus lower performance may be associated with higher VOMS symptom scores. Finally, higher-level mobility tasks (eg, running and rapid changes of direction) require increased dynamic balance and may place higher demand on the vestibular and oculomotor systems. As a result, lower performance on tests measuring higher-level mobility may be expected by those with vestibular or oculomotor deficits and symptom complaints captured by the VOMS.

Determining whether the VOMS relates to different levels of balance control from quiet stance to physically demanding activities is an appropriate next step in validating the usefulness of this assessment tool. Therefore, the purpose of this study was to (1) compare self-reported VOMS symptom scores in adults with persistent mTBI symptoms and healthy controls; and (2) explore the relationship of VOMS symptom scores with the self-reported DHI, performance on balance, gait, and higher-level mobility assessments in an adult population with persistent mTBI symptoms. We hypothesized that (1) adults with persistent mTBI complaints would report more symptoms following each of the VOMS test items than controls, and (2) that VOMS symptoms would positively relate to self-reported DHI symptoms and negatively relate to performance on clinical assessments (ie, Functional Gait Analysis [FGA], and instrumented evaluation of balance and gait) and higher-level mobility tasks (ie, modified [narrowed] Illinois Agility Task [mIAT] and the Revised High-Level Mobility Assessment Tool [HiMAT-R]).

METHODS

Study design

This cross-sectional study was completed across 3 separate sites (Oregon Health & Science University, Portland, Oregon; Courage Kenny Research Center, Minneapolis, Minnesota; and University of Utah, Salt Lake City, Utah) between June 2019 and September

2020. Data were collected as part of a larger study relating to return-to-duty assessments and evaluating functional performance in civilian and military relevant tasks (NCT03892291, W81XWH1820049).[27] Participants completed a single testing session. The study was conducted in accordance with the Declaration of Helsinki (1964) and approved by the institutional review boards at each of the sites. Informed consent was obtained prior to participation.

Inclusion and exclusion criteria

Detailed inclusion and exclusion criteria have been defined in the study protocol.[27] Briefly, participants were included if they were 18 to 50 years of age and were free of medical conditions (eg, musculoskeletal disorder, psychological disorder, substance abuse, subjective reporting of significant pain) that may affect balance, with the exception of recent mTBI for the mTBI group. Diagnosis of mTBI was based upon Veterans Affairs and Department of Defense criteria, with all mTBI participants expressing persistent symptoms beyond the acute stage (>3 weeks).[28]

Participants

A convenience sample of 53 symptomatic individuals with mTBI and 57 healthy controls was recruited and tested across the 3 separate sites. Participants were recruited from the general population of the hospitals and local communities surrounding each of the sites and through concussion clinics or medical records of individuals with an mTBI diagnosis associated with each of the institutions. To reduce the chance of participants over- or understating symptoms, participants were not provided with any individual study data; however, they were compensated 50 to 75 dollars depending on test site for their participation in the main study.[27]

Procedure

All participants were tested on a single occasion in a clinical laboratory space or quiet hallway adjacent to the laboratory. Demographic information, exercise screening, and medical history (eg, injury mechanism and any clinical diagnosis of comorbidities such as anxiety) were collected via self-report. Participants completed the VOMS per published instructions,[1] self-reported symptoms using the DHI,[29] clinical balance[30] and gait tests,[25,31] and higher-level mobility tasks.[32–36]

Vestibular ocular motor screening

For the VOMS, we assessed (1) smooth pursuit, (2) horizontal saccades, (3) vertical saccades, (4) near point convergence (NPC), (5) horizontal vestibular ocular reflex (VOR), (6) vertical VOR, and (7) visual motion sensitivity (VMS). Symptoms were rated before and after each item. The NPC distance was also measured. The outcome measures of the VOMS were the post–item symptom scores, which were defined as the sum of the post–item symptoms across domains, resulting in post–item symptom scores for each test item (7 scores total). For example, post–item VMS symptoms = VMS headache + VMS dizziness + VMS nausea + VMS fogginess. Total VOMS symptoms were also calculated as the sum of all post–item symptoms across all domains and all test items. The NPC distance was measured in centimeters using an Accommodation Near Point Rule (Good-Lite Co, Elgin, Illinois) as the point at which the patient reported doubling of the 14-point font target or the eyes were observed to break convergence. The average of 3 trials was used.

Dizziness Handicap Inventory

The DHI is a 25-item self-reported symptom questionnaire relating to dizziness that is used in clinical and research applications to capture long-term deficits related to vestibular and oculomotor dysfunction.[29] The DHI can be evaluated as the total score and 3 subdomains explaining functional, emotional, and physical limitations.

Balance assessment

Balance was quantified during 30 seconds of quiet stance with feet together performed with eyes closed on a firm surface and on 10-cm foam surface (Airex Balance-pad Elite; Airex AG, Sins, Switzerland) using a lumbar-worn inertial motion sensor (Opal v2; APDM Wearable Technologies, Inc, Portland, Oregon). Sway area was used as the outcome of interest, which was exported from Mobility Lab (APDM Wearable Technologies).[30] Sway area is a common metric used in instrumented measurement of postural sway[37] and was chosen because of the ease at which it can be interpreted and the ability of sway area to differentiate between populations with mTBI compared with healthy matched controls, particularly in stances with eyes closed.[38]

Gait assessments

Gait was evaluated using the FGA[25] and gait speed. The FGA was performed as it includes more complex gait tasks (eg, walking with yaw or pitch plane head rotations), which may be more likely to provoke the vestibular system and result in lower FGA scores.[25] The FGA was performed according to clinical guidelines.[25] The test was scored out of a total of 30 points, with a

total score of 30/30 being the highest and indicative of better performance.[25]

Gait speed was determined using a 1-minute walk test at a comfortable self-selected pace between 2 lines that were 6 m apart and quantified using sensors worn on both the feet and lumbar area. Gait speed was exported from Mobility Lab (APDM Wearable Technologies).[31] Gait speed was chosen as the metric of interest as it is a widely reported metric in mTBI research, and deficits have generally been found in populations with mTBI compared with healthy matched controls.[38,39]

Higher-level mobility assessments

Higher-level mobility was assessed using 2 tests: (1) HiMAT-R[32–34] and (2) mIAT.[35,36] The HiMAT-R was conducted per guidelines.[32–34] The test was scored out of a possible 32 points, with a total score of 32/32 being the highest and indicative of better performance.[32–34] The mIAT was a short running agility test[27] that was quantified using a stopwatch. The time taken to complete the mIAT was the measure of interest, with a faster speed reflecting better performance. The HiMAT-R was chosen because of the inclusion of exercises such as running, backward walking, skipping, and bounding. The mIAT was chosen because of the rapid changes of direction required. The involvement of these activities was hypothesized to place higher demand on the vestibular and oculomotor systems.

Statistical analysis

Independent-samples *t* tests or nonparametric Mann-Whitney tests for ordinal data were used to examine between-groups differences in VOMS post–item scores and NPC. To examine the relationships between the ordinal scale VOMS symptom scores and other measures in the mTBI group, nonparametric partial correlations were used (Spearman's rho) while controlling for age and time since injury. Our sample size was based on power analysis conducted for the broader study[27]; however, this is an exploratory analysis of secondary outcome measures. We used an α level of .05 and a false discovery rate correction to account for running multiple statistical tests. Benjamini-Hochberg adjusted *P* values are presented. Statistical procedures were completed using R-Studio (version 1.2.5042; Boston, Massachusetts).

RESULTS

Description of sample

Our healthy controls were matched demographically for age, height, and mass (see Table 1). Twelve percent of our healthy controls had sustained a previous concussion a median 13 (min = 4, max = 17) years before testing and reported no residual symptoms. Compared with the healthy controls, the mTBI group indicated more symptoms on the DHI and had higher subscores and performed worse on balance, gait, and higher-level

TABLE 1 *Group characteristics for participants with mTBI and healthy controls*

	mTBI	Control	
Demographics			
n (%) (male)	53 (21)	57 (28)	
Age, mean (SD), y	32.0 (9.6)	31.1 (9.5)	
Height, mean (SD), m	1.7 (0.3)	1.7 (0.1)	
Mass, mean (SD), kg	72.1 (21.6)	72.4 (17.1)	
Days since concussion[a]	261 [21-989]	4564 [1441-6105]	…[b]
Self-reported symptoms[a]			
Total DHI	14 [0-58]	0 [0-10]	…[b]
DHI functional	4 [0-22]	0 [0-4]	…[b]
DHI emotional	2 [0-22]	0 [0-0]	…[b]
DHI physical	6 [0-20]	0 [0-8]	…[b]
Balance			
Sway area—firm, mean (SD), m^2/s^4	0.17 (0.21)	0.09 (0.04)	…[b]
Sway area—foam, mean (SD), m^2/s^4	0.62 (0.85)	0.29 (0.12)	…[b]
Gait			
FGA total score[a]	28 [21-30]	29 [24-30]	…[b]
Gait speed, mean (SD), m/s	1.29 (0.18)	1.35 (0.13)	…[b]
Higher-level mobility			
HiMAT-R (total score)[a]	25 [11-32]	27 [17-32]	…[b]
mIAT time, mean (SD), s	25.0 (4.3)	22.8 (2.7)	…[b]

Abbreviations: DHI, Dizziness Handicap Inventory; FGA, Functional Gait Assessment; HiMAT-R, Revised High-Level Mobility Assessment Tool; mIAT, modified Illinois Agility Test; mTBI, mild traumatic brain injury.

[a] Reported as median [min-max].

[b] $P < .05$.

mobility tasks. Additional between-group information such as level of physical activity and comorbidities is provided in Supplemental Digital Content Table 1 (available at: http://links.lww.com/JHTR/A514).

Between-group differences in VOMS post–item symptom scores

The mTBI group reported significantly more symptoms following each item of the VOMS, and the point of convergence occurred significantly further away (all *P*s < .001; see Table 2). Convergence distance in the mTBI group (mean = 10.8 cm, SD = 9.6) occurred significantly further away than for the healthy controls (mean = 4.9 cm, SD = 4.0; *P*s < .001).

Association between VOMS item scores and other measures

Strong positive relationships were found between the DHI scores (total, functional, emotional, and physical) and the post–item symptoms as well as the sum of VOMS symptoms (rho = 0.53-0.68, *P* < .001; see Table 3). No significant relationships existed between VOMS measures (including NPC distance) and measures of balance, gait, and higher-level mobility (see Table 3).

DISCUSSION

This study had 2 aims: (1) to compare the differences between self-reported VOMS symptom scores in adults with persistent mTBI symptoms and healthy controls; and (2) explore the relationship of VOMS symptom scores with the self-reported DHI, performance on balance, gait, and higher-level mobility assessments in an adult population with persistent mTBI symptoms. For aim 1, we found significant between-group differences between the control group and our age-diverse mTBI group, with the mTBI group reporting more post–item symptoms after each of the VOMS items and a higher VOMS total score. With regard to aim 2, we found the VOMS was associated with the subjective DHI questionnaire; however, it was not associated with any objective measures of balance, gait, or higher-level mobility.

Between-group differences in VOMS post–item symptom scores

As hypothesized, compared with the control group, our age-diverse mTBI group reported more post–item symptoms after each of the VOMS items, resulting in a higher VOMS total score. These findings in our older cohort are consistent with those in younger athletic populations[1,40–42] and support the utility of the VOMS as a clinical measure for the adults aged 18 to 50 years with mTBI persistent symptoms. Despite originally being developed as a screening tool for the purpose of distinguishing between concussed and healthy adolescents,[1–7] our findings support the relevance of the VOMS for the screening of vestibular/oculomotor symptoms following mTBI in an age-diverse sample and outside the initial acute mTBI time frame. While unlikely to be used for the purpose of sideline screening in adults, in a clinical setting, our findings indicate the VOMS may be useful in screening the existence of vestibular and oculomotor symptoms in this sample for the purpose of aiding clinical subtyping and prescribing rehabilitation.

TABLE 2 *Descriptive statistics and between-group differences for VOMS post–item symptom scores*

	Control	mTBI	*t*/*z*	*P*[a]
Smooth pursuit[b]	0 [0-4]	5 [0-19]	−7.66[c]	<.001
Horizontal saccades[b]	0 [0-5]	5 [0-17]	−7.66[c]	<.001
Vertical saccades[b]	0 [0-4]	5 [0-20]	−7.53[c]	<.001
Convergence[b]	0 [0-6]	5 [0-20]	−7.86[c]	<.001
Horizontal VOR[b]	0 [0-8]	6 [0-22]	−7.28[c]	<.001
Vertical VOR[b]	0 [0-6]	6 [0-22]	−7.89[c]	<.001
VMS[b]	0 [0-8]	7 [0-21]	−7.37[c]	<.001
Total VOMS symptoms[b]	0 [0-40]	39 [0-131]	−7.55[c]	<.001
NPC distance	4.9 (4.0)	10.8 (9.6)	−4.16	<.001

Abbreviations: NPC, near point of convergence; VMS, visual motion sensitivity; VOMS, Vestibular/Ocular Motor Screening; VOR, vestibular ocular reflex; mTBI, mild traumatic brain injury.
[a] Benjamini-Hochberg adjusted *P* value.
[b] Reported as median [min-max].
[c] *z*-score associated with the Mann Whitney test.

TABLE 3 *Partial correlations between VOMS items and other measures, controlling for age and days since injury*[a]

	DHI				Balance		Gait		Higher-level mobility	
	Total	Functional	Emotional	Physical	Sway area (firm)	Sway area (foam)	FGA total	Gait speed	HiMAT-R	mIAT
Smooth pursuit	**0.66**	**0.59**	**0.57**	**0.62**	−0.26	−0.13	0.13	0.23	− 0.08	0.11
Horizontal saccades	**0.67**	**0.58**	**0.62**	**0.62**	−0.21	−0.10	0.06	0.15	− 0.02	− 0.01
Vertical saccades	**0.67**	**0.59**	**0.60**	**0.65**	−0.27	−0.07	0.09	0.23	− 0.01	0.01
Convergence	**0.63**	**0.55**	**0.60**	**0.57**	−0.22	−0.12	0.06	0.14	0.03	0.01
Horizontal VOR	**0.64**	**0.54**	**0.63**	**0.57**	−0.17	−0.07	0.03	0.13	0.00	0.07
Vertical VOR	**0.65**	**0.57**	**0.60**	**0.60**	−0.25	−0.12	0.11	0.20	− 0.06	0.11
VMS	**0.63**	**0.53**	**0.60**	**0.59**	−0.21	−0.11	0.00	0.14	0.00	0.06
Total VOMS symptoms	**0.68**	**0.58**	**0.63**	**0.62**	−0.23	−0.11	0.07	0.18	− 0.02	0.06
NPC distance	0.16	0.20	0.09	0.10	−0.29	−0.05	0.02	0.01	− 0.14	0.21

DHI, Dizziness Handicap Inventory; FGA, Functional Gait Assessment; HiMAT-R, Revised High-Level Mobility Assessment Tool; mIAT, modified Illinois Agility Test; VMS, visual motion sensitivity; VOR, vestibular ocular reflex.

[a]**Bold font** = $P < .001$ after Benjamini-Hochberg adjustment.

Association between VOMS item scores and other measures

We were correct in our hypothesis that VOMS symptoms would positively relate to self-reported symptoms in the DHI. Albeit an expected finding, because the DHI focuses on vestibular symptoms and the focus of the VOMS is vestibular and oculomotor screening, this finding is promising as it suggests symptoms evoked during the VOMS relate to patients' perceived disability. We were surprised, however, that the VOMS did not relate to our objective measures of balance, gait, and higher-level mobility. Given that removal of vision increases dependence on the vestibular and somatosensory systems,[43,44] we expected to see a relationship between sway area and higher provocation of symptoms throughout the VOMS. Similarly, we expected to see poorer gait performance (lower FGA and slower gait speed) associated with higher vestibular and oculomotor symptoms during the VOMS. These hypotheses were not supported by our data. The FGA measures more complex gait tasks that may be more likely to provoke the vestibular system and result in lower FGA scores[25] such as walking with yaw or pitch plane head rotations or turning and stopping, which can be provocative for individuals with vestibular complaints.[26] Still, despite the reliance on vestibular function for these tasks, the associations were not strong, nor significant in this population.

We also did not see any relationship between the VOMS and higher-level mobility tasks that place higher demand on the vestibular and oculomotor systems.[45] As expected, individuals with mTBI performed significantly worse than healthy controls on each of the higher-level mobility tasks and as such it is possible that these symptomatic individuals slowed down during these tasks in an effort to reduce any provocation of their vestibular/visual symptoms. However, given the lack of strong consistent relationships with VOMS measures, we speculate that these tasks are capturing different features of dysfunction in these participants.

Clinical implications

The VOMS was originally designed for screening for acute concussion in adolescents; however, research teams and clinicians are now using this measure in known mTBI populations, across ages, and to monitor mTBI recovery (eg, PI: Kontos, #NCT02634944; PI: King, #NCT03479541).[8,17] Our findings provide supporting evidence for the ability of the VOMS to capture subjective symptoms of vestibular and oculomotor dysfunction in adults with persistent mTBI symptoms. Furthermore, the association between the VOMS symptoms and perceived disability captured by the DHI helps validate the ability of the VOMS to capture vestibular

dysfunction in this population. Nonetheless, the limited association between VOMS symptoms and our measures of functional performance suggests that VOMS symptoms may not represent function in more dynamic and physically demanding tasks. Taken together, conducting the VOMS in a clinic in adults with persistent mTBI (1) may help identify a need to address vestibular or oculomotor function during rehabilitation; (2) may aid assessment of vestibular and oculomotor dysfunction by provoking symptoms in individuals who are not forthcoming in their reporting of symptoms; however, (3) should not be used in place of, but rather evaluated together with other measures of function.

Limitations and directions for future research

There are 2 main limitations that we acknowledge due to this study being a secondary exploration of data collected from a larger study. The first of these is that while the age demographic of our sample was older than the population in the majority of studies that have evaluated the VOMS, we recognize that there may be limitations with not including adults older than 50 years. We therefore recommend further investigation in elderly populations should clinicians wish to use the VOMS in this age group. The second is that the power and sample sizes were specific to the main study.[27] As we found group differences and associations after α correction, we do not believe this to be a significant limitation and feel that the data herein may provide values that can be used for powering future investigations in adults.

Clinical phenotypes of mTBI were not considered in this study. Given emerging research on phenotypes of concussion,[46–48] it is possible that stratifying by subtype would elicit different results. While this was beyond the scope of this article, we suggest that it may be an interesting avenue for future work. With increased focus and use of the VOMS in concussion/mTBI research, future work should consider consensus on the exact test protocol and VOMS scoring that should be used. Anecdotal evidence suggests variation among research teams and clinicians. For instance, presence or absence of a 10-second wait time after completion of a test item before symptom severity questions for horizontal and vertical VOR.[1,49]

CONCLUSION

The aims of this study were to compare self-reported VOMS symptom scores between healthy control adults and those with persistent mTBI symptoms and to explore the relationship of VOMS symptom scores with the self-reported DHI and performance on balance, gait, and higher-level mobility assessments in an adult population with persistent mTBI symptoms. There were distinct differences in VOMS symptoms between our control and mTBI groups and significant correlations between the VOMS post–item scores and DHI total and subdomain symptom scores. However, limited relationships existed between the VOMS post–item scores and objective measures of balance, gait, and higher-level mobility. These findings suggest that symptom provocation during the VOMS is not associated with functional performance on these tasks and that each of these activities is capturing different constructs. These findings help support the use of the VOMS as one component of a full evaluation in adults aged 18 to 50 years suffering from persistent mTBI symptoms. Research in this space is relatively new and unanswered questions remain, such as responsiveness to recovery and normative data across ages.

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