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Association of Multidomain Assessment Outcomes With Referral for Vestibular Therapy After Concussion

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Context: Multiple aspects of a multidomain assessment have been validated for identifying concussion; however, researchers have yet to determine which components are related to referral for vestibular therapy.

Objective: To identify which variables from a multidomain assessment were associated with receiving a referral for vestibular therapy after a concussion.

Design: Retrospective chart review, level of evidence 3.

Patients or Other Participants: Participants (n = 331; age = 16.9 ± 7.2 years; 39.3% female) were diagnosed with a concussion per international consensus criteria by a clinical neuropsychologist after presenting to a concussion specialty clinic.

Main Outcome Measure(s): Medical chart data were extracted from the first clinical visit regarding preinjury medical history, computerized neurocognition, Post-Concussion Symptom Scale, Concussion Clinical Profiles Screen, and Vestibular Ocular Motor Screening within 16.2 ± 46.7 days of injury. We built 5 backwards logistic regression models to associate the outcomes from each of the 5 assessments with referral for vestibular therapy. A final logistic regression model was generated using variables retained in the previous 5 models as potential predictors of referral for vestibular therapy.

Results: The 5 models built from individual components of the multidomain assessment predicted referral for vestibular therapy (R^2 = 0.01–0.28) with 1 to 6 statistically significant variables. The final multivariate model (R^2 = 0.40) retained 9 significant variables, represented by each of the 5 multidomain assessments except neurocognition. Variables that had the strongest association with vestibular therapy referral were motor vehicle accident mechanism of injury (odds ratio [OR] = 15.45), migraine history (OR = 3.25), increased headache when concentrating (OR = 1.81), and horizontal vestibular ocular reflex (OR = 1.63).

Conclusions: We demonstrated the utility of a multidomain assessment and identified outcomes associated with a referral for vestibular therapy after a concussion.

Key Words: mild traumatic brain injury, Post-Concussion Symptom Scale, Concussion Clinical Profiles Screen, Vestibular Ocular Motor Screening

Key Points

- Referrals for vestibular therapy are becoming an increasingly common treatment for patients after concussion.
- We identified critical components of a multidomain assessment that were associated with vestibular therapy referral from a concussion specialty clinic.
- Motor vehicle accident mechanism, migraine history, reporting eye strain, and provocative horizontal vestibular ocular reflex testing were the strongest predictors of vestibular therapy referral.

Concussion is a heterogeneous injury characterized by a wide range of impairments and associated physical, cognitive, and emotional symptoms that aggregate into various clinical profiles or subtypes.[1] These subtypes are used to guide targeted treatment for the individual's unique injury response, rather than using a homogeneous treatment approach for all patients.[1] The American Medical Society for Sports Medicine characterized 6 common subtypes from existing research on the topic: vestibular, ocular, headache or migraine, anxiety or mood, fatigue, and cognitive.[1] Given the obvious differences among these impairments and their associated symptoms, expert consensus is that a comprehensive, multidomain assessment is necessary to evaluate and manage patients with concussions.[2,3] Further, growing appreciation exists among clinicians who treat patients with concussion regarding the need to engage with clinical specialists for certain subtypes, with the goal of targeting treatments to the individual's specific post–concussion concerns. One primary example is referral to a physical therapist who specializes in the vestibular and ocular system, as some degree of vestibular or ocular (or both) motor impairment is present in 60%–90% of patients.[4–6]

After concussion, the vestibular and ocular motor subtypes frequently occur together, and profile scores for these subtypes display a large correlation.[6,7] Concussion can interfere with the integration of these systems and lead to similar symptoms, including dizziness and blurred vision, and potentially impairments in other domains (eg, neurocognition).[6] Vestibular and ocular-motor problems can be debilitating, and recent researchers[8] have suggested that patients with vestibular or ocular impairments after concussion are more likely to also experience emotional changes. This evidence reinforces the need for a validated, multidomain assessment for concussion, but little evidence describes the variables that are associated with referral for specialized therapies. Using the example of vestibular and ocular subtypes of concussion, provocation of these systems during the initial clinical assessment should be a strong predictor of referral for vestibular or ocular therapy.

The Vestibular Ocular Motor Screening (VOMS) tool is a 5-minute assessment that has accrued empirical support since its initial development and validation in 2014.[9] Items on the VOMS include smooth pursuits, saccades, near point of convergence (NPC), vestibular ocular reflex (VOR), and visual motion sensitivity (VMS) measurement. Clinical cutoffs for VOMS items have been validated in adolescent[9] and collegiate athlete[7,10] populations for the purposes of discriminating patients with active concussions from healthy control groups. However, although vestibular or ocular symptoms or impairments are common after concussion, not all patients experience them. Therefore, the VOMS may have more precise clinical utility for identifying patients with vestibular or ocular dysfunction necessitating therapeutic referral to a specialist. Despite this, no current evidence indicates that VOMS items are useful for discriminating between patients who require a referral to vestibular or ocular therapy after concussion and those who do not require a referral. Also, scarce available evidence associates other aspects of the multidomain assessment (eg, medical history, symptoms, neurocognition) with referral for specialized therapies.

The primary purpose of our study was to determine which variables from a multidomain assessment (eg, demographics or medical history, neurocognition, symptoms, and vestibular ocular motor provocation) were associated with patients who were referred for vestibular therapy after presenting to a concussion specialty clinic. We expected that some combination of the VOMS items (ie, horizontal vestibular ocular reflex [HVOR], vertical vestibular ocular reflex [VVOR], and visual motor sensitivity [VMS]) would be associated with referral. Because earlier investigators[11–14] suggested that vestibular or ocular dysfunction postconcussion was associated with certain risk factors (eg, motion sickness, migraines, female sex), we hypothesized that self-reporting motion sickness, migraine history, ocular history, or female sex would be related to vestibular therapy referral.

METHODS

Participants

This retrospective chart review used consecutive patient data from an electronic health record via concussion specialty clinics from January 2019 to February 2020. Participants ranged from 9 to 68 years of age. To be included in the study, participants had to have a current, symptomatic concussion at the time of the first clinical evaluation for which data were extracted. Exclusion criteria were prior brain surgery, moderate to severe traumatic brain injury, neurologic disorder, treatment for substance abuse, a history of concussion within the 3 months before the first clinical visit, or a history of 3+ concussions. The study was reviewed and approved by the university institutional review board. Participants and parents (if necessary) provided written consent for involvement.

Measures

Demographics and Medical History. Participants self-reported demographics (age and sex), medical history (history of attention-deficit/hyperactivity disorder or learning disability, motion sickness, migraine, ocular dysfunction, depression, anxiety, and number of prior concussions [0–3]), and injury-specific information (days since injury and mechanism of injury) in a standardized clinical interview.

Concussion Clinical Profiles Screen.[15] The Concussion Clinical Profiles Screen (CP-Screen) is a valid and reliable 29-item self-report symptom inventory. Each item is scored on a 4-point Likert scale ranging from 0 (*none*) to 3 (*severe*). Five clinical profile scores are calculated: anxiety or mood, cognitive or fatigue, migraine, vestibular, and ocular, along with 2 modifier scores (cervical and sleep).

Computerized Neurocognitive Assessment. Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) was used to evaluate neurocognitive performance. This instrument assesses symptoms using the Post-Concussion Symptom Scale (PCSS), a 23-item self-report symptom survey that is scored on a 7-point Likert scale (0 = *none*, 6 = *severe*). Neurocognitive performance is evaluated with respect to verbal and visual memory, visual motor speed, and reaction time domains. The 2 scales are reliable and valid measures of neurocognition and concussion symptom severity, respectively.

Concussion Diagnosis and Referral for Vestibular Therapy. Participants were diagnosed with a current concussion by a clinical neuropsychologist per consensus guidelines including a clear mechanism of injury, initial signs and symptoms, and being currently symptomatic or impaired.[3] The clinical neuropsychologist identified the patient's concussion subtype based on the results of a clinical interview and a symptom questionnaire designed to identify concussion clinical subtypes.[15] Extensive information on the assignment of a concussion subtype to guide targeted intervention can be found elsewhere.[2,7,16] Consistent with the standard of care at the clinic, patients were referred for vestibular therapy by the neuropsychologist if they reported (1) critical symptoms (slow, wavy dizziness or fast, "room-spinning" dizziness; mental "fogginess"; or eye fatigue), (2) functional impairment (discomfort in busy environments, discomfort in busy visual fields such as scrolling on a cellphone, feelings of unsteadiness, avoidance behaviors, or double or blurry vision when reading), or (3) a high symptom burden after VOMS testing.[17]

Vestibular Ocular Motor Screening Tool.[9] The VOMS is a brief screening tool that assesses vestibular and ocular motor symptoms and impairments via smooth pursuits, horizontal or vertical saccades, NPC, HVOR or VVOR, and VMS. The NPC distance is measured in centimeters and calculated as an average of 3 trials. Participants self-report headache, dizziness, nausea, and fogginess on a 0 to 10 scale before taking the VOMS, for a total pretest range of 0 to 40. These symptoms are rescored after each test, and the pretest symptoms are subtracted from each posttest symptom score to obtain a measure of symptom provocation from the test.

Statistical Analysis

For descriptive purposes, we used Mann-Whitney U tests to compare cohorts for continuous variables due to a

Table 1. Descriptive Statistics for Overall Sample (n = 331)

Variable	Value, n (%)[a]
Age, mean ± SD, y	16.9 ± 7.2
Female sex	130 (39.3)
Time to first visit, mean ± SD, d	16.2 ± 46.7
Recovery, mean ± SD, d	37.6 ± 41.6
Mechanism of injury	
Sport	239 (72.2)
Fall or accident	51 (15.4)
Motor vehicle accident	19 (5.7)
Assault	10 (3.0)
Other	12 (3.6)
Loss of consciousness	36 (10.9)
Posttraumatic amnesia	50 (15.1)
Disorientation	39 (11.8)
Confusion	35 (10.6)
Attention-deficit/hyperactivity disorder or learning disorder	45 (13.6)
Motion sickness	70 (21.1)
Migraine	62 (18.7)
Ocular dysfunction	27 (8.2)
Depression	28 (8.5)
Anxiety	67 (20.2)
Prior concussion	106 (32.0)

[a] Except where otherwise indicated.

nonnormal distribution (ie, age, time to first visit, and days to recovery). The χ^2 analyses were conducted with associated odds ratios (ORs) and 95% CIs for the categorical variables (ie, sex, mechanism of injury, medical history, and primary subtypes). Five logistic regressions were built to identify the association of different components of the multidomain assessment (ie, demographics or medical history from a clinical interview, CP-Screen symptom items, PCSS symptom items, computerized neurocognitive domains, and VOMS items) with referral for vestibular therapy. A sixth logistic regression model was generated using predictors retained from any of the previous 5 models to assess which variables from the multidomain assessment were most associated with vestibular referral. We adopted an all-possible regression approach for all models in this study to rule out the potential for order effects from stepwise methods. Specifically, we used the best subsets model selection method from SPSS (version 28; IBM Corp), in which the best set of predictors was selected based upon the Akaike information criterion corrected value.[18] The smallest value was selected as the best performing model. Post hoc diagnostics included ensuring that the variance inflation factor of all included variables was below a mean of 4.0 and partial correlations were below $r = 0.8$.[19,20] For all analyses, $P < .05$ was considered statistically significant.

RESULTS

Descriptive Statistics

Participants (n = 331) were 16.9 ± 7.2 years old, 39.3% were female (n = 130), and they presented to the clinic 16.2 ± 46.7 days after their most recent concussion (Table 1). Regarding their medical history, 32.0% reported a prior concussion (n = 106); 21.1%, motion sickness history (n = 70); and 8.2%, ocular disorder (n = 27). Approximately 17.5% of patients demonstrated vestibular symptoms or impairments that necessitated referral for vestibular therapy.

The demographics and risk factors of patients referred to vestibular therapy versus those who were not referred are shown in Table 2. Compared with participants who were not referred for vestibular therapy, those who were referred were older, had higher odds of a concussion history (OR = 1.81), and took longer to recover. Those referred for vestibular therapy were less likely to have a sport-related mechanism of injury (OR = 0.77) and more likely (OR = 11.97) to have experienced a motor vehicle accident. Patients referred for vestibular therapy were more likely to have a vestibular ocular primary subtype (OR = 1.90–3.26) and less likely to have a cognitive or migraine primary subtype (OR = 0.15–0.36).

Logistic Regression Models From Each Multidomain Assessment

The results for each logistic regression model to associate individual multidomain assessment models with vestibular therapy referral are provided in Table 3. The model associating demographic or medical history variables with vestibular therapy referral ($R^2 = 0.08$; $P < .001$) retained 3 variables overall and 2 statistically significant variables (migraine history: OR = 1.93; motor vehicle accident: OR = 14.4).

The model associating CP-Screen variables with vestibular therapy referral ($R^2 = 0.15$; $P < .001$) retained 3 statistically significant variables (feeling sad: OR = 1.58; dizziness: OR = 1.58; increased headache when concentrating: OR = 1.70).

The model associating computerized neurocognitive domains with vestibular therapy referral ($R^2 = 0.01$; $P = .03$) retained 1 statistically significant variable (visual memory score: OR = 0.98).

The model associating PCSS items with vestibular therapy referral ($R^2 = 0.07$; $P < .001$) retained 2 statistically significant variables (more emotional: OR = 1.26; slowed down: OR = 1.27).

The model associating VOMS items with vestibular therapy referral ($R^2 = 0.28$; $P < .001$) retained 5 statistically significant variables (ORs = 1.33 for horizontal saccades [HSAC], 0.52 for NPC symptoms, 1.16 for NPC distance, 1.53 for HVOR, and 1.29 for VMS).

Final Logistic Regression Model Including Retained Variables From 5 Prior Models

The model associating retained variables from each multidomain assessment with vestibular therapy referral ($R^2 = 0.40$; $P < .001$) can be seen in Table 4. The model retained 9 statistically significant variables (ORs = 3.25 for migraine history, 15.45 for motor vehicle accident, 1.42 for HSAC, 0.46 for NPC symptoms, 1.18 for NPC distance, 1.63 for HVOR, 1.26 for VMS, 1.37 for more emotional [PCSS], = and 1.81 for increased headache when concentrating [CP-Screen]).

DISCUSSION

Recent evidence[21] suggested that targeted vestibular therapy for the treatment of post–concussion vestibular symptoms or impairments leads to greater clinical improvements than behavioral management alone. However, a key concern for the sports medicine professional is identifying a clinical endpoint for when and how to determine when a

Table 2. Demographics and Risk Factors of Patients Referred Versus Not Referred for Vestibular Therapy

Variable	Vestibular Therapy Referral, Median (Interquartile Range) Yes (n = 102)	No (n = 229)	Odds Ratio	95% CI	*P* Value
Age, y	16 (14, 20)	15 (13, 17)	NA	NA	<.001[b]
Female sex	45 (44.1)	85 (37.1)	1.34	0.83–2.15	.23
Time to first visit, d	9 (5, 21)	5 (3, 9)	NA	NA	<.001[b]
Recovery, d	41.5 (24, 81)	19 (12, 32.5)	NA	NA	<.001[b]
Mechanism of injury[a]					
Sport	61	178	0.77	0.65–0.92	.001[b]
Fall or accident	15	36	0.94	0.54–1.63	.81
Motor vehicle accident	16	3	11.97	3.57–40.19	<.001[b]
Assault	4	6	1.50	0.43–0.81	.52
Other	6	6	2.25	0.74–6.79	.14
Attention-deficit/hyperactivity disorder or learning disorder	14 (13.7)	31 (13.7)	1.01	0.51–1.98	.99
Motion sickness	26 (25.5)	44 (19.4)	1.50	0.86–2.62	.15
Migraine	27 (26.5)	35 (15.3)	2.00	1.13–3.52	.71
Ocular dysfunction	10 (9.8)	17 (7.4)	1.36	0.60–3.07	.47
Depression	11 (10.8)	17 (7.7)	1.48	0.67–3.30	.33
Anxiety	23 (22.5)	44 (19.6)	1.20	0.68–2.12	.53
Prior concussion	42 (41.2)	64 (27.9)	1.81	1.11–2.94	.02[b]
Primary subtype[b]					
Anxiety or mood	3	18	0.37	0.11–1.24	.09
Fatigue or cognitive	1	15	0.15	0.02–1.12	.03[b]
Migraine	17	106	0.36	0.23–0.57	<.001[b]
Vestibular	58	40	3.26	2.34–4.52	<.001[b]
Ocular	22	26	1.90	1.13–3.19	.02[b]
Cervical	0	2	NA	NA	NA
Multiple	1	2	1.12	0.02–21.81	.92
None	0	20	NA	NA	NA

Abbreviation: NA, odds ratio not calculated due to zero-count cells in the vestibular referral group.
[a] Single variable compared with all others.
[b] Significant at $P < .05$.

referral for specialized care is indicated.[6] In the present study, we demonstrated how the administration of a multidomain assessment after concussion can be useful for identifying clinical variables associated with a vestibular therapy referral. At least 1 variable from each assessment domain was retained in the final multivariate model except for computerized neurocognition (Table 4). Consistent with our hypotheses, multiple VOMS items were associated with referral for vestibular therapy (ie, HSAC, HVOR, NPC symptoms, NPC distance, and VMS). These results can be used to inform sports medicine clinicians as to when a referral for specialized vestibular therapy may be warranted after concussion.

Common vestibular impairments after concussion are dizziness, lightheadedness, vertigo, nausea, imbalance, and disequilibrium.[1] These symptoms are typically reduced at rest but are provoked by dynamic movement or environmental stimuli such as changes in support surface or high-intensity visual demand.[17,22] As such, provocative testing of vestibular ocular and vestibular-visual integration via the VOMS is typically needed to identify vestibular dysfunction after a concussion. This notion is supported by our final regression model (Table 4), which retained 2 primarily vestibular VOMS assessments (ie, HVOR and VMS) and 2 primarily ocular VOMS assessments (ie, HSAC and NPC symptoms or distance). Additionally, none of the traditional vestibular symptoms from the CP-Screen or PCSS were retained in the final model. Clinicians should be aware of the tight integration between the visual and vestibular systems and recognize that primarily ocular symptoms or impairments may also reflect an impairment in the vestibular system.

Interestingly, patients referred for vestibular therapy in this study were associated with a history of migraine but not concussion or motion sickness (when analyzed with univariate analyses; Table 2). Medical history is an important component of the multidomain concussion assessment, as researchers have shown that certain preinjury factors can exacerbate the impairment or symptom burden during concussion assessments. For example, motion sickness predicted vestibular dysfunction after concussion and increased false-positive rates during VOMS testing.[11,13] A history of migraines can also lead to false-positive results on baseline VOMS assessments in healthy athletes.[14,23] However, our findings ultimately suggest that, although it is important for clinicians to recognize an athlete's history may predispose the individual to certain symptoms and impairments, their actual manifestation on clinical examination is most pertinent to the assignment of targeted therapies.

An important outcome was the association of multiple emotional or mood symptoms with referrals for vestibular therapy. Vestibular dysfunction can be a stressful experience, potentially resulting in activity avoidance due to an increase in vestibular symptoms. Authors[24] of a recent study reported that emotional symptoms on the Dizziness Handicap Inventory were related to provocation on VOMS assessment in adolescents after concussion. Further, Eagle et al[25] demonstrated that vestibular symptoms on the VOMS were associated with the anxiety or mood

Table 3. **Results of 5 Backwards Logistic Regression Models to Predict Vestibular Therapy Referral Using Multidomain Assessment**

Variable	Odds Ratio	95% CI	*P* Value
Demographics or medical history			
Migraine history	1.93	1.06–3.53	.032[a]
Prior concussion(s)			
0 (reference value)	1	NA	NA
1	1.74	0.97–3.13	.065
2	1.33	0.54–3.33	.531
3	1.50	0.28–8.12	.639
Motor vehicle accident	14.4	4.02–51.32	<.001[a]
Concussion Clinical Profiles Screen symptoms			
Feeling sad	1.58	1.03–2.40	.034[a]
Dizziness	1.58	1.15–2.16	.004[a]
Increased headache when concentrating	1.70	1.28–2.28	<.001[a]
Visual aura	1.43	1.01–2.03	.042[a]
Neurocognitive domains			
Visual memory score	0.98	0.97–0.99	.026[a]
Post-Concussion Symptom Scale symptoms			
Slowed down	1.27	1.08–1.50	.004[a]
More emotional	1.26	1.07–1.48	.005[a]
Vestibular Ocular Motor Screening change scores			
Visual motion sensitivity	1.29	1.09–1.54	.003[a]
Horizontal saccades	1.33	1.05–1.67	.016[a]
Horizontal vestibular ocular reflex	1.53	1.23–1.90	<.001[a]
Near point of convergence symptoms	0.52	0.38–070	<.001[a]
Near point of convergence distance	1.16	1.09–1.25	<.001[a]

Abbreviation: NA, not available.

[a] Significant at $P < .05$.

concussion subtype. Earlier researchers[26] also determined that patients with more sleep symptoms were more likely to have vestibular and mood concussion subtypes. Avoiding typical activities can result in internalizing affective symptoms and a potential mood disorder.[8] Clinicians should be aware that vestibular symptoms can also increase mood symptoms and consider screening for mood disorders in patients who need a vestibular referral after a concussion.

Limitations

This study had limitations worth noting. The multidomain assessment protocol described here is the standard of care for the concussion specialty clinics that were involved in this study; as such, the clinician who referred for vestibular therapy was aware of the patients' scores. Referral is a multifaceted clinical decision and should not be based upon VOMS scores alone. We evaluated a large age range of participants to increase generalizability across the population that experiences concussion. Future investigators should examine the predictive value of a multidomain assessment in high-risk concussion populations, such as adolescent and collegiate athletes and military populations. Also, we included patients across a wide range (1–384 days) of time since injury. Future authors should explore the predictive utility of VOMS item changes across recovery periods (ie, acute, subacute, or chronic). Finally, the current data were obtained from a concussion specialty clinic and may not be generalizable to other clinical settings, such as on-field assessments, emergency departments, or primary care physicians' offices.

Table 4. **Backwards Logistic Regression Model to Predict Vestibular Ocular Therapy Referral Using All Variables**

Variable	Odds Ratio	95% CI	*P* Value
Migraine history	3.25	1.39–7.56	.006[a]
Motor vehicle accident	15.45	3.31–71.00	.001[a]
Increased headache when concentrating	1.81	1.26–2.58	<.001[a]
More emotional	1.37	1.12–1.67	.002[a]
Visual motion sensitivity	1.26	1.04–1.52	.018[a]
Horizontal saccades	1.42	1.10–1.83	.007[a]
Horizontal vestibular ocular reflex	1.63	1.29–2.07	<.001[a]
Near point of convergence symptoms	0.46	0.32–0.66	<.001[a]
Near point of convergence distance	1.18	1.10–1.28	<.001[a]

[a] Significant at $P < .05$.

CONCLUSIONS

Increasing empirical evidence shows that the application of early treatment and more rapid referrals for specialty care, such as vestibular therapies, can be beneficial after concussion.[21,22] Patients with vestibular or ocular impairments postconcussion may benefit from targeted vestibular and oculomotor therapies.[16,27] In addition to several VOMS items, in the current study, we demonstrated that patients with a concussion from a motor vehicle accident or a history of migraine and those who were feeling more emotional were associated with receiving a referral for vestibular therapy. Using validated clinical tools as part of a multidomain assessment can assist in facilitating timely referral for specialty therapies for patients with vestibular or ocular dysfunction after concussion.

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