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# The Ability of Vestibular and Oculomotor Screenings to Predict Recovery in Patients After Concussion: A Systematic Review of the Literature

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***Objective:*** The objective of this systematic review was to investigate if a positive vestibular or oculomotor screening is predictive of recovery in patients after concussion.

***Data Sources:*** Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to search through PubMed, Ovid MEDLINE, SPORTDiscus, and the Cochrane Central Register of Controlled Trials (CENTRAL) and hand searches of included articles.

***Study Selection:*** Two authors evaluated all articles for inclusion and assessed their quality using the Mixed Methods Assessment Tool.

***Data Extraction:*** After quality assessment was completed, the authors extracted recovery time, vestibular or ocular assessment results, study population demographics, number of participants, inclusion and exclusion criteria, symptom scores, and any other outcomes of assessments reported in the included studies.

***Data Synthesis:*** Data were critically analyzed by 2 of the authors and categorized into tables regarding the ability of researchers of each article to answer the research question. Many patients who have vision, vestibular, or oculomotor dysfunction appear to have longer recovery times than patients who do not.

***Conclusions:*** Researchers routinely reported that vestibular and oculomotor screenings are prognostic of time to recovery. Specifically, a positive Vestibular Ocular Motor Screening test appears to consistently predict longer recovery.

***Key Words:*** vestibular, concussion, recovery, traumatic brain injury



**Key Points**

- A positive Vestibular Ocular Motor Screening (VOMS) consistently demonstrated to be an indicator of longer recovery compared to a negative test.
- Clinicians should incorporate vestibular and ocular motor screenings into their assessment for concussion as it is a prognostic factor of prolonged recovery from concussion and reliably elicits concussive symptoms in patients.

Patients who are diagnosed with a concussion often present with vestibular and oculomotor symptoms during the initial diagnosis. Specific symptoms of the vestibular and oculomotor system include eye movement abnormalities such as saccadic[1] and eye-tracking dysfunction[2,3] and vision abnormalities including vision reaction time[4] and pupillary light reflex.[5] Rates of vision dysfunction have been reported at 62%,[6] oculomotor dysfunction at 21% to 69%,[1,6] and vestibular dysfunction at 81%[7] after concussion. Although these rates include patients who sustained a concussion during a motor vehicle accident or accident at the home, school, or work, most patients sustained a sport-related concussion.[1,6] Several symptoms are indicative of vestibular or oculomotor dysfunction, including blurred vision, visual problems, and double vision.[8] Some researchers have reported dizziness in approximately 50% to 80% of diagnosed concussions.[9,10]

Vision and vestibular symptoms have been investigated as prognostic factors for recovery from concussive injury,[11] with researchers of one scoping review suggesting that vestibular and oculomotor testing can indicate the need for further testing that could predict recovery.[12] Other injury characteristics reported in one systematic review to be associated with recovery were total symptom severity, headache severity, and dizziness severity. Symptom severity is the most frequently studied and strongest predictor of time to recovery.[13] It is difficult for clinicians to gain a full picture of the symptoms and dysfunctions that a patient is presenting with and to give patients a prognosis without considering the multisystemic nature of concussive injury.

Often during a clinical evaluation, a multimodal assessment will appropriately inform clinical decision-making. Vestibular and visual symptoms are often present in patients after concussion, and clinicians can assess impairments related to these systems. Several tools are available to clinicians to assess the vestibulospinal, vestibulo-ocular, and oculomotor systems. To assess the vestibulospinal system, clinicians often use the Balance Error Scoring System,[14] sensory organization test,[15,16] Romberg test,[17] Concussion Balance Test,[18] or the tandem gait test.[19] Some of these tests are included in the most recent sideline concussion assessment tool (SCAT5)[20] and have been previously validated.[14,17] Similar to the vestibulospinal system, the vestibulo-ocular system has multiple tests that clinicians can use to assess patients. Clinicians can assess horizontal and vertical vestibular ocular reflex (VOR) and visual motion sensitivity to challenge the vestibulo-ocular system. Finally, the oculomotor system can be assessed using horizontal and vertical saccades, near point of convergence (NPC), accommodation, smooth pursuit, and pupillometry. Currently no single test is suitable to screen patients for all these subdomains of vestibulo-ocular and oculomotor systems.

The Vestibular Ocular Motor Screening tool (VOMS) enables clinicians to assess many of the subdomains of the vestibulo-ocular and oculomotor systems. The VOMS has demonstrated that it is reliable and functionally allows clinicians to measure most of the vestibular system and monitor a patient's vestibular system recovery.[21] Thus, when clinicians use the VOMS, they can gain a substantial understanding of which symptoms are provoked after each oculomotor task and which symptoms patients may be the most sensitive to. However, to date, no investigators have specifically examined (via a systematic review or meta-analysis) the ability of the VOMS or vestibular or oculomotor assessments within the VOMS to predict recovery from concussion. Thus, our question is as follows: Do patients who present with a positive vestibular or oculomotor screening, or single test within a vestibular or oculomotor screening, after concussion have a longer recovery time than patients with a negative vestibular or oculomotor screening?

## METHODS

### Search Strategy

This systematic review was completed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[22] This review was registered in PROSPERO (no. CRD42022306344). The databases searched include PubMed, Ovid MEDLINE, SPORTDiscus, and the Cochrane Central Register of Controlled Trials (CENTRAL). The search terms used include VOMS, concussion, recovery, vestibular, vision, saccades, NPC, visual motion sensitivity, and King-Devick. The specific searches were concussion AND VOMS AND recovery, concussion and King-Devick AND recovery, and concussion AND vestibular OR vision OR saccades OR near point convergence OR visual motion sensitivity. In addition to the searches of databases, hand searches of reference lists of all relevant articles were conducted. The initial searches were conducted in January 2022. Follow up searches of PubMed were conducted in July 2022.

### Selection Criteria and Quality Assessment

The inclusion criteria were studies of humans in which researchers assessed patients with the VOMS or another vestibular or oculomotor screening, recorded duration of recovery from concussion, English language, limited to the past 10 years (2012 to 2022), and level 4 evidence or higher based on the Centre for Evidence-Based Medicine scale.[23] Exclusion criteria were studies in which researchers examined rehabilitation effects on recovery. The results from the database searches were exported and inputted into Covidence systematic reviewer software (Veritas Health Innovation). Once the results were imported, 2 authors (M.B. and T.V.M.) screened the titles, abstracts, and full text for inclusion. The Mixed-Methods Appraisal Tool[24] was used to assess the quality of studies and was performed within Covidence (Veritas Health Innovation).

### Data Extraction

The primary data extracted from the studies included recovery time, vestibular or oculomotor scores, and other objective or subjective measures taken by clinicians or reported by patients, such as postconcussion symptom score, patient-report outcome measures, and cognitive or balance assessments. Secondary data extracted from the studies included the number of patients, patient demographics, study design, start and end date, inclusion and exclusion criteria, and method of recruitment. The data extraction was performed through Covidence and was organized by individual study. Each of the articles was evaluated, and the data were extracted and inputted into the individual data extraction tables in Covidence. If it was impractical to extract the data from within Covidence, such as that embedded in a large table, an Excel spreadsheet was used.

### Data Synthesis and Analysis

Once data were extracted, the authors critically evaluated each of the articles for commonalities and differences, focusing specifically on the extracted variables. The data from included studies were reviewed for a possible meta-analysis; however, the methods and statistical analyses used in individual studies did not allow for the extraction of similar data to perform a meta-analysis. A qualitative synthesis of the findings was used to summarize the conclusions. Articles were categorized into 2 groups based on the study design and comparators used. The groups included studies comparing typical and prolonged recovery and studies assessing recovery over time with a positive or negative initial vestibular or oculomotor screening finding.

## RESULTS

Figure 1 presents the flow diagram based on the PRISMA guidelines. The literature search retrieved 1612 articles published between January 1, 2012, and January 2, 2022. We removed 684 duplicates and screened 937 studies. After we screened titles and abstracts, we assessed 42 articles for inclusion based on their full text. Two articles were included in the full text screening after a review of the author's personal article databases. After a full text evaluation, we included 18 articles in the review (Tables 1–3).

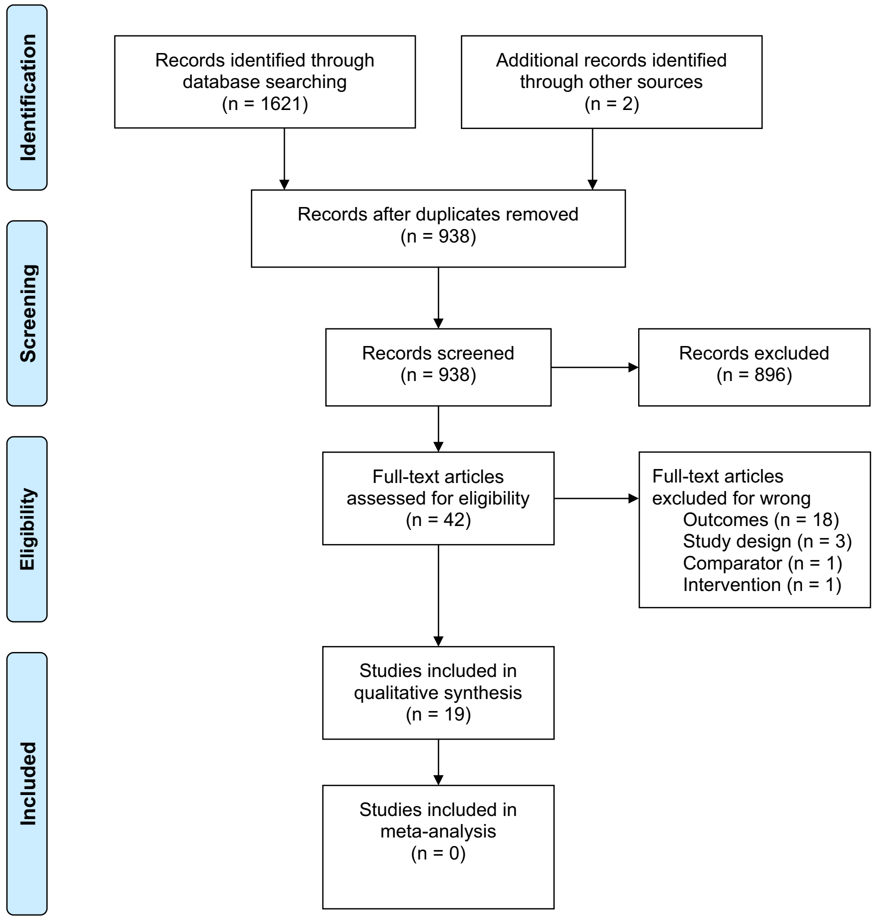


**Figure. PRISMA flow diagram.**

## Quality Assessment

The Mixed-Methods Appraisal Tool was used to evaluate each study for its quality (Tables 4–6). All the included studies had representative samples of their respective populations of interest and used appropriate measurements. Most of the included studies had complete outcome data, except 4 studies.[25–28] Although most studies had complete outcome data, a few had adequate controls for confounding variables.[26,27,29–34] Finally, for all of the studies, exposures occurred as intended with the exception of one study[26] in which this aspect could not be determined.

## Time of Assessment and Operationalization of Positive Screening

In all of the included studies, the authors conducted vestibular or oculomotor screening assessments at either the time of injury or during the initial clinic encounter. Researchers of some studies included subsequent screenings at follow-up visits. For our purposes we did not operationalize a positive or negative vestibular or oculomotor screening assessment. However, several studies (Büttner et al,[35] Eagle et al,[30] Glendon et al,[36] Henry et al,[25] Price et al,[11] Sinnott et al,[37] Whitney et al,[38] and Worts et al[39]) used the VOMS cutoff of greater than a 2-symptom score increase described by Mucha et al.[21] Other authors (Anzalone et al,[40] Leddy et al,[26] Master et al,[41] and Martinez et al[34]) chose to dichotomize patients based on any symptom provocation. Cheever et al,[28] Glendon et al,[36] and Sufrinko et al[32] did not disclose which they used, and Knell et al[31] examined different cut points for the VOMS.

## Studies Comparing Typical and Prolonged Recovery

Researchers of nine of the included studies dichotomized patient populations into typical and prolonged recovery. The most common cutoff for typical vs prolonged recovery was less than or equal to 28 days and greater than 28 days used in 3 studies.[29,33,39] Martinez et al[34] used less than 29 days and greater than or equal to 29 days; Price et al,[11] Ellis et al,[27] and Eagle et al[30] used less than or equal to 30 days and greater than 30 days as their recovery cutoff; Leddy et al[26] stratified at 21 days; Cheever et al[28] stratified at 16 days; and Sufrinko et al[32] stratified patients into groups of less than 15 days, 15 to 29 days, and greater than 29 days until recovery. For our purposes, we used the stratification by Sufrinko et al[32]; we combined cutoff groups of less than 15 days and 15 to 29 days into one group of less than or equal to 29 days.

Among studies that dichotomized recovery, researchers of only 3 studies (Leddy et al,[26] Sufrinko et al,[32] and Worts et al[39]) investigated the association between a positive test of smooth pursuits at initial presentation and recovery. In 2 studies, the authors found a significant relationship between positive smooth pursuits at initial presentation and prolonged recovery, with Worts et al noting higher symptom provocation from smooth pursuits among the prolonged

**Table 1. Studies Comparing Typical and Prolonged Recovery** **Continued on Next page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| Cheever et al[28] | Prospective cohort | Diagnosed with SRC, 11 to 20 y old, assessed within 14 days of concussion. | Vestibular or ocular motor pathologic condition; brain surgery; ophthalmic surgery; neurological, cognitive, or behavioral disorders; or TBI graded more severe than concussion | Years experience:<br>Healthy control, 10.55 ± 5.4 y<br>Acute concussion, 6.11 ± 6.2 y<br>Prolonged recovery, 6.88 ± 3.1 y<br>Previous concussions:<br>Healthy control, 0.34 ± 0.8<br>Acute concussion, 0.95 ± 1.1<br>Prolonged recovery, 4 ± 3.3 | Healthy vs prolonged recovery:<br>NPC at initial visit, $P = .004$<br>NPC at 2 weeks postinjury, $P = .01$<br>NPC at 6 weeks postinjury, $P = .043$ | Vestibular and oculomotor assessments demonstrate continued impairment after clinical recovery particularly in patients with a prolonged recovery. |
| DuPrey et al[29] | Case control | | Lost to follow up; strabismus, amblyopia, ocular surgery, intracranial hemorrhage, neurologic or ocular surgery, vestibular disorder, substance abuse, migraine headache, learning disability (including ADD/ADHD), psychiatric or mood disorder (not including depression and anxiety), and NPC greater than 15 cm at time of recovery measured in the office after SRC. | Normal NPC 49.6%, n = 134<br>Abnormal NPC 50.4%, n = 136<br>Days to initial evaluation:<br>Normal NPC, 4.6 ± 3.3 days<br>Abnormal NPC, 5.8 ± 4.9<br>Symptom severity:<br>Normal NPC, 14.5 ± 4.6<br>Abnormal NPC, 43.1 ± 9.5<br>Number of symptoms:<br>Normal NPC, 7.8 ± 3.3<br>Abnormal NPC, 15.1 ± 4.2 | Recovery:<br>Normal NPC, 19.2 ± 14.7 days<br>Abnormal NPC, 51.6 ± 53.9 days<br>NPC at initial visit:<br>Normal NPC, 4.1 ± 1.3 cm<br>Abnormal NPC, 12.3 ± 4.7cm<br>Prolonged recovery:<br>Normal NPC, 11.9% (n = 16)<br>Abnormal NPC, 62.5% (n = 85) | When measuring convergence insufficiency, it may predict prolonged recovery and can be a useful tool for assessing concussion. |
| Eagle et al[30] | Retrospective chart review | Patients between 12 and 17 y of age with a diagnosed, symptomatic concussion per current consensus guidelines (n = 232). | Patients with a moderate-to-severe TBI, neurological disorder, or preexisting vestibular disorder. | % Female:<br>Early, 43 (30%)<br>Late, 49 (60%)<br>History of motion sickness:<br>Early, 38 (26%)<br>Late, 17 (21%)<br>Anxiety or depression:<br>Early, 19 (13%)<br>Late, 9 (11%)<br>ADHD or learning disability:<br>Early, 9 (6%)<br>Late, 5 (6%)<br>Headache or migraine history:<br>Early, 52 (36%)<br>Late, 30 (37%) | Adjusted OR for prolonged recovery:<br>VMS, 5.18; 95% CI = 1.52, 17.60 | Patients with a positive VMS were 5 times more likely to have a prolonged recovery than those who did not. |
| Ellis et al[27] | Retrospective cross sectional | Patient aged 19 y or younger, diagnosis of acute SRC or of persistent symptoms. | Patients with intracranial hemorrhage or traumatic structural spinal injury.<br>Patients who suffered a second concussion during follow-up for a previous symptomatic concussion. | Mean age:<br>Acute SRC, 13.7 ± 2.2 y<br>PCS, 16 ± 1.6 y<br>% Female:<br>Acute SRC, 30% (n = 23)<br>PCS, 63% (n = 15)<br>VOD:<br>Acute SRC, 29% (n = 22)<br>PCS, 63% (n = 15) | Association between length of recovery and VOD. Displayed as OR (95% CI):<br>Crude, VOD only 8.89 (2.61, 26.29)<br>Age, 8.92 (2.73, 29.11)<br>Female, 8.41 (2.62, 27.07)<br>Previous concussion, 9.45 (2.97, 30.06) | Patients who presented with a vestibular oculomotor dysfunction were 8 times more likely to have persistent symptoms after recovery than patients who did not. |

**Table 1. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
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| | | | Patients with coexistent neuroopthalmological conditions.<br>Patients in whom other coexistent medical conditions that prevented return to play. | Previous concussion:<br>Acute SRC, 47% (n = 36)<br>PCS, 54% (n = 13)<br>Median PCS score:<br>Acute SRC, 10 (3–25 range)<br>PCS, 33 (14.5–47.5 range) | Previous migraine, 9.94 (3.06, 32.32)<br>Amnesia, 7.17 (2.15, 23.83)<br>LOC, 8.29 (2.6, 26.44) | |
| Knell et al[31] | Prospective case series | Patients aged 8–18 y, participating in a sport at time of injury, diagnosed with an SRC and evaluated within 7 days from initial date of injury | Previous diagnosis of developmental delay, diagnosis of comorbid neck or spine injuries, previous diagnosis of congenital or acquired neurological defect or injury not related to the concussion injury, inability to understand the premise of the study due to language barriers. | Median recovery time (IQR):<br>Normal recovery, 18 (13–23) days<br>Protracted recovery ,43 (35–52) days<br>Median time since injury (IQR):<br>Normal recovery, 2 (1–4) days<br>Prolonged recovery,<br>3 (2–5) days<br>Age:<br>Normal recovery: 8–12 y, 29.7% (n = 121); 13–18 y, 70.3% (n = 286)<br>Prolonged recovery: 8–12 y, 21.8% (n = 31); 13–18 y, 78.2% (n = 111)<br>Female sex:<br>Normal recovery, 39.7% (n = 162)<br>Prolonged recovery, 53.3% (n = 76)<br>Sport:<br>Normal recovery, noncontact, 10.3% (n = 43); contact, 39.1% (n = 159); collision, 42.5% (n = 172)<br>Prolonged recovery, noncontact, 18.3% (n = 26); contact, 43% (n = 61); collision, 8.5% (n = 12) | 1-Unit increase in symptoms from VOMS:<br>Males, Exp(0.3223846) = 1.38 days longer recovery or unit increase ($P < .001$)<br>Females, Exp(0.548789) = 1.73 days longer recovery or unit increase ($P < .001$)<br>Symptom provocation, mean ± SD, Males:<br>Smooth pursuits, 0.89 ± 1.58<br>Horizontal saccades, 1.65 ± 2.43<br>Vertical saccades, 2.02 ± 2.75<br>Convergence, 2.27 ± 4.34<br>Horizontal VOR, 2.96 ± 3.56<br>Vertical VOR, 3.01 ± 3.78<br>VMS, 4.05 ± 4.44<br>Symptom provocation, mean ± SD, females<br>Smooth pursuits, 1.37 ± 2.01)<br>Horizontal saccades 2.20 ± 2.91<br>Vertical saccades 2.62 ± 3.14<br>Convergence, 3.02 ± 4.49<br>Horizontal VOR 3.57 ± 3.54<br>Vertical VOR, 3.82 ± 3.7<br>VMS, 4.62 ± 3.99 | In patients who do not test positive on the VOMS, they have a 90% chance for a normal recovery. |
| Leddy et al[26] | Prospective cohort | Patients with acute concussion (AC) included male and female adolescent athletes (aged 13–19 years) who sustained SRC within 1–10 days of initial visit at the University Concussion Management Clinic | (1) Evidence of focal neurological deficit;<br>(2) inability to exercise on the treadmill due to other injury;<br>(3) known heart disease or increased cardiac risk;<br>(4) current diagnosis of ADHD, learning disorder, depression, or anxiety; | Days to recovery, mean ± SD:<br>Acutely concussed, 26.19 ± 38.27 days<br>Normal recovery, 13 ± 6.82 days<br>Delayed recovery, 75.36 ± 62.55 days<br>Mean ± SD symptom score, visit 1:<br>Acutely concussed, 31.25 ± 22.89 | Initial visit delayed vs normal recovery physical exam findings<br>Convergence OR, 5.5352 (1.1022, 37.7497), $P = .019$<br>Second visit delayed vs normal recovery physical exam findings | Patients who tested positive on the smooth pursuits or near point convergence at the second visit were 41 times and 19 times more likely, respectively, to have a delayed recovery than those who did not. |

**Table 1. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
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| | | and were evaluated by a study physician who diagnosed the concussion according to the 4th International Conference on Concussion in Sport | (5) history of moderate or severe TBI;<br>(6) use of medications that affect cardiac output (eg, beta blockers); or<br>(7) greater than 3 prior concussions (because this is associated with delayed recovery). | Normal recovery, 25.22 ± 19.16<br>Delayed recovery, 53.73 ± 22.23<br>Mean ± SD symptom score, visit 2:<br>Acutely concussed, 8.31 ± 15.06<br>Normal recovery, 2.54 ± 5.93<br>Delayed recovery, 29.82 ± 19.26 | Smooth pursuits OR, 41.8147 (4.0001–2221.5053), $P = .0001$<br>Convergence OR, 19.8356 (3.1593–173.7532), $P = .0002$<br>Tandem gait OR, 70.2308 (3.4588–1426.0205), $P = .0002$ | |
| Martinez et al[34] | Retrospective cohort | Adolescent- and college-aged patients who self-presented or referred to the sports concussion clinic at the Duke Sport Sciences Institute between July 2013 and January 2015.<br>Medical diagnosis of concussion and willingness to receive a battery of questionaries and follow-up. | None disclosed. | Gender (n):<br>Delayed recovery: F = 34, M = 46<br>Nondelayed recovery: F = 23, M = 60<br>Age (y):<br>Delayed recovery, 16.47 ± 4.36<br>Nondelayed recovery, 16.02 ± 2.81<br>Neck disability index score (%):<br>Delayed recovery, 21.08 ± 14.3<br>Nondelayed recovery, 21.21 ± 26.23<br>Dizziness handicap inventory (%):<br>Delayed recovery, 30.47 ± 17.97<br>Nondelayed recovery, 28 ± 25.7<br>Symptom number:<br>Delayed recovery, 9.57 ± 7.38<br>Nondelayed Recovery, 4.7 ± 5.88<br>Time from injury to exam (days):<br>Delayed recovery, 17.1 ± 37.43<br>Nondelayed recovery, 4.07 ± 6.43 | Clinical symptoms and delayed recovery OR (95% CI)<br>Headache, 3.53 (1.08, 11.47), $P = .04$<br>Dizziness, 2.14 (1.13, 4.02), $P = .02$<br>Cognitive impairments, 2.72 (1.4, 5.28), $P < 0.01$<br>Clinical exam findings and delayed recovery (OR):<br>Cognitive testing, 3.52 (1.08, 11.48), $P = .04$<br>Visual testing, 2.98 (1.31, 6.8), $P < .01$<br>Vestibular testing, 4.28 (2.18, 8.43), $P < .01$ | Some symptoms and parts of a comprehensive clinical exam can identify patients who are more likely to have a delayed recovery. Vestibular testing and cognitive impairments at initial examination were the most consistent predictors of delayed recovery. |
| Price et al[11] | Retrospective cohort | None disclosed | Developmental delays other than ADDs or learning disabilities (ie, autism spectrum disorder, muscular dystrophy), comorbid neck or spine injuries, and congenital or acquired neurological defects not related to the concussion injury (ie, brain tumor, epilepsy). | Recovery time (IQR) 19 days (14–28):<br>Protracted recovery<br>No, 77.2% (n = 88)<br>Yes, 22.8% (n = 26)<br>Sex<br>Male, 64% (n = 73)<br>Female, 36% (n = 41)<br>Sport:<br>Nonsport, 2.6% (n = 3)<br>Noncontact, 7.9% (n = 9)<br>Contact, 58.8% (n = 67)<br>Collision, 30.7% (n = 35)<br>Hx concussion: | Incidence rate ratio (95% CI):<br>Positive VOMS<br>Fully adjusted, 1.31 (1.05, 1.63)<br>Age adjusted, 1.22 (0.96, 1.55)<br>Crude<br>1.22 (0.96, 1.55)<br>Positive King-Devick<br>Fully adjusted, 1.02 (0.85, 1.24)<br>Age adjusted, 1.09 (0.88, 1.34)<br>Crude, 1.08 (0.87, 1.33) | A positive VOMS screening resulted in a 1.31-day longer recovery than those who had a negative VOMS screening.<br>A negative VOMS screening was a useful predictor of normal recovery. |

**Table 1. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
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| | | | | No, 75.4% (n = 86)<br>Yes, 24.6% (n = 28)<br>Time to presentation (IQR):<br>2 days (2–4) | | |
| Sufrinko et al[32] | Cohort study | Athletes between the ages of 12 and 22 years, who had sustained their SRC during an organized sports practice or competition within the past 7 days. | Athletes with no clear mechanism of injury, prior brain surgery, neurological disorder, vestibular or ocular motor condition, treatment for substance abuse, psychiatric condition. | Age:<br>≤14 day recovery, 15.7 ± 2.1 y<br>15–29 day recovery, 15.2 ± 1.7 y<br>30–90 day recovery, 15.0 ± 1.9 y<br>Male sex:<br>≤14 day recovery, 81% (n = 22)<br>15–29 day recovery, 64% (n = 16)<br>30–90 day recovery, 76% (n = 13)<br>Time until presentation:<br>≤14 day recovery, 3.3±1.9 days<br>15–29 day recovery, 3.6 ± 1.9 days<br>30–90 day recovery, 4.2 ± 1.8 days<br>No hx of concussion:<br>≤14 day recovery, 52% (n = 14)<br>15–29 day recovery, 72% (n = 18)<br>30–90 day recovery, 71% (n = 12)<br>Migraine:<br>≤14 day recovery, 15% (n = 4)<br>15–29 day recovery, 12% (n = 3)<br>30–90 day recovery, 12% (n = 2) | VOMS 30–90 day recovery predictors:<br>Smooth pursuits: $\beta$ = .405; SE= 0.565; $P <$ .001; OR, 1.5; 95% CI = 1.19, 1.9<br>Horizontal saccades: $\beta$ = .404; SE = 0.117; $P$ = .001; OR, 1.5; 95% CI = 1.19, 1.88<br>Vertical saccades: $\beta$ = .356; SE = 0.105; $P$ = .001; OR, 1.43; 95% CI = 1.16, 1.75<br>Convergence distance: $\beta$ = .192; SE = 0.088; $P$ = .029; OR, 0.12; 95% CI = 1.02, 1.44<br>Horizontal VOR: $\beta$ = .271; SE = 0.086; $P$ = .002; OR, 1.31; 95% CI = 1.11, 1.55<br>Vertical VOR: $\beta$ = .253; SE = 0.079; $P$ = .001; OR, 1.29; 95% CI = 1.10, 1.51<br>VMS: $\beta$ = .21; SE = 0.063; $P$ = .001; OR, 1.23; 95% CI = 1.09, 1.4 | Vertical saccades were a good predictor or concussion recovery. However, vestibular and oculomotor testing were not as robust predictors of recovery as symptom clusters. |
| Walker et al[33] | Retrospective cross sectional | Patients with a concussion if they were <19 y of age and presented to clinic for evaluation within 14 days of injury | Patients who sustained a concussion from a non-sports-like related mechanism, had trauma-related pathology on neuroimaging, or sustained a second head injury before full recovery from the index concussion. | Age:<br>Normal NPC, 15.7 ± 1.7 y<br>Receded NPC, 14.9 ± 1.5 y<br>Female sex:<br>Normal NPC, 46% (n = 21)<br>Receded NPC, 47% (n = 36)<br>Time until presentation:<br>Normal NPC, 6.8 ± 3.1 days<br>Receded NPC, 7 ± 3.6 days<br>Hx previous concussion:<br>Normal NPC, 59% (n = 27)<br>Receded NPC, 45% (n = 35)<br>ADHD:<br>Normal NPC, 4% (n = 2)<br>Receded NPC, 16% (n = 12)<br>Hx anxiety<br>Normal NPC, 4% (n = 2)<br>Receded NPC, 16% (n = 12) | Symptom severity:<br>Normal NPC, 15.8<br>Receded NPC, 23.7<br>NPC break point:<br>Normal NPC, 3.7 ± 1.8 cm<br>Receded NPC, 11.1 ± 6.2 cm<br>NPC recovery point:<br>Normal NPC, 6.2 ± 2.1 cm<br>Receded NPC, 13.9 ± 7.1 cm<br>mBESS errors:<br>Normal NPC, 5.2 ± 4.1 errors<br>Receded NPC, 7.2 ± 5.2 errors<br>Single-task tandem gait time:<br>Normal NPC, 21.9 ± 8.7 seconds<br>Receded NPC, 23.8 ± 8.4 seconds | When assessing patients within 14 days of concussive injury, a receded NPC appears predictive of symptom burden and possible longer recovery. |

**Table 1. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| | | | | | Dual-task tandem gait time:<br>Normal NPC, 32.3 ± 15.2 seconds<br>Receded NPC, 33.0 ± 12.6 seconds | |
| Worts et al[39] | Retrospective cohort | Athletes aged 13 to 18 y old sustaining a sport-related concussion and presented for evaluation within 7 days of injury to an outpatient clinic between November 2013 and April 2019. | It was later determined that their initial visit occurred >7 days since their injury (n = 25), they did not return for full medical clearance (n = 47), or it was determined that their injury occurred outside the context of sport participation (n = 2). | Recovery duration:<br>Normal recovery, 16.5 ± 5.8 days<br>Prolonged recovery, 42.4 ± 12.3 days<br>Time until presentation:<br>Normal recovery, 3.5 ± 1.8 days<br>Prolonged recovery, 4 ± 1.9 days<br>Age:<br>Normal recovery, 15.3 ± 1.3 y<br>Prolonged recovery, 15.1 ± 1.5 y<br>Male sex:<br>Normal recovery, 72% (n = 112/156)<br>Prolonged recovery, 40% (n = 18/45)<br>Hx migraine:<br>Normal recovery, 10% (n = 15/153)<br>Prolonged recovery, 9% (n = 4/45)<br>Hx mood disorder:<br>Normal recovery, 5% (n = 8/154)<br>Prolonged recovery, 16% (n = 7/45)<br>Loss of consciousness:<br>Normal recovery, 16% (n = 25/152)<br>Prolonged recovery, 2% (n = 1/44) | Smooth pursuits symptom provocation:<br>Normal recovery, 0.4 ± 1.4<br>Prolonged recovery, 1.2 ± 1.7<br>Horizontal saccades symptom provocation:<br>Normal recovery, 1.1 ± 1.9<br>Prolonged recovery, 2.3 ± 2.1<br>Vertical saccades symptom provocation:<br>Normal recovery, 1.5 ± 2<br>Prolonged recovery, 2.4 ± 3.1 | Symptom provocation from smooth pursuits, horizontal saccades, and vertical saccades at initial presentation is predictive of prolonged recovery in patients after a concussion. |

Abbreviations: ADDs, attention-deficit disorders; ADHD, attention-deficit/hyperactivity disorder; Hx, History IQR, interquartile range; LOC, level of consciousness; PCS, pelvic congestion syndrome; TBI, traumatic brain injury; VOD, veno-occlusive disease.

**Table 2. Studies Assessing Continuous Recovery After Positive Vestibular or Oculomotor Screening** Continued on Next page

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| Anzalone et al[40] | Prospective cohort | Diagnosed with SRC, 11 to 20 y old, assessed within 14 days of concussion. | Vestibular or ocular motor pathologic condition; brain surgery; ophthalmic surgery; neurological, cognitive, or behavioral disorders; or TBI graded more severe than concussion | Boys, 58.7% (n = 98)<br>Girls, 41.3% (n = 69)<br>Prior concussion, 29.9 % (n = 50)<br>Sport participation:<br>Basketball, 11.4% (n = 19)<br>Football, 42.5% (n = 71)<br>Soccer, 19.2% (n = 32)<br>Other, 27% (n = 45) | VOMS measures, Univariate HR:<br>Smooth pursuits, 0.65 (0.47–0.9)<br>Horizontal saccades, 0.68 (0.5–0.94)<br>Vertical saccades, 0.55 (0.4–0.75)<br>Horizontal VOR, 0.68 (0.49–0.94)<br>Vertical VOR, 0.6 (0.44–0.83)<br>NPC, 0.7 (0.46–1.08)<br>Accommodation, 0.79 (0.55–1.16)<br>Vestibular 0.55 (0.4–0.76)<br>Ocular motor 0.45 (0.32–0.63)<br>Recovery time:<br>Negative VOMS recovery, 13.4 ± 8.2 days<br>Positive VOMS recovery, 23.0 ± 13.4 days | Any positive test on the VOMS except accommodation and NPC was associated with an increased recovery time. |
| Glendon et al[36] | Prospective cohort | Rugby athletes who sustained a concussion during the 2019–2020 season. | None disclosed | Age:<br>All athletes, 20.5 ± 1.5 y<br>SRC, 20.62 ± 3.5 y<br>Male sex:<br>All athletes, 65.7% (n = 92)<br>SRC, 61.4 (n = 25)<br>Previous concussion:<br>All athletes, 75% (n = 90)<br>SRC, 73.8% (n = 31)<br>Learning disability:<br>All athletes, 25% (n = 35)<br>SRC, 14.3% (n = 6) | Wilcoxon sign rank testing (median VOMS score after concussion):<br>2 days, 3.0 (0–20.5), $z = -4.375$, $P = .000$<br>4 days, 3.0 (0–12.25), $z = -4.707$, $P = .000$<br>8 days, 0.0 (0–3), $P < .005$ | University athletes' symptom burden after concussion returned to near baseline around 8 days postconcussion along with vestibular and oculomotor functioning. |
| Master et al[41] | Retrospective cohort | A total of 432 randomly selected pediatric patients out of a total 3430 patients, representing a 13% sample, aged 5 to 18 y who presented within 1 y of injury with a new diagnosis of concussion using the International | Patients with intracranial hemorrhage or previous neurologic surgery | Sex:<br>Females, 59% (n = 253)<br>Males, 41% (n = 179)<br>Age:<br>14 (IQR 12–16)<br>Comorbidities:<br>Motion sickness, 28% (n = 123)<br>Migraine, 18% (n = 80)<br>Anxiety, 16% (n = 69) | Median time to recovery<br>+VOR, 107 days<br>−VOR, 53, days<br>+Balance, 107 days<br>−Balance, 47 days<br>+Accommodative amplitude, 150 days<br>−Accommodative amplitude, 81 days<br>+Smooth pursuits, 95 days | Patients who present with NPC, accommodation, VOR, smooth pursuits, or saccadic dysfunction were significantly more likely to take longer to recover than patients who did not. |

**Table 2. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| | | Classification of Diseases, Ninth Revision codes 850.0, 850.1, 850.11,850.12, 850.2, 850.3, 850.4, 850.5, or 850.9 to The Children's Hospital of Philadelphia Minds Matter Concussion Program between July 1, 2014, and June 1, 2016. | | Depression, 11% (n = 47)<br>ADD, 9% (n = 39)<br>Physical exam deficits at presentation:<br>Saccades, 82% (n = 355)<br>Balance, 68% (n = 285)<br>Smooth pursuits, 66% (n = 285)<br>VOR, 66% (n = 275)<br>NPC, 35% (n = 147)<br>Accommodation, 22% (n = 93)<br>Time to resolution, 86 (IQR 40–146) | −Smooth pursuits, 60 days | |
| Sinnott et al[37] | Prospective case series | Complete a clinical assessment within 10 days of injury; second clinical visit at 11–21 days after concussion; medical clearance evaluation as determined by treating physician. | Concurrent cervical spine injury or positive neuroimaging | Groups:<br>None, n = 20<br>Improve, n = 12<br>Persist, n = 17<br>Age:<br>None, 14.3 ± 1.9 y<br>Improve, 15.8 ± 2.3 y<br>Persist, 15.6 ± 2.1 y<br>Female:<br>None, 20% (n = 4)<br>Improve, 58.3% (n = 7)<br>Persist, 58.8% (n = 10)<br>Previous concussion<br>None 12.2% n = 6<br>Improve 2% n = 1<br>Persist 14.3% n = 7<br>Motion sickness:<br>None, 15% (n = 3)<br>Improve, 50% (n = 6)<br>Persist, 35.3 (n = 6)<br>Migraine:<br>None, 15% (n = 3)<br>Persist, 29.4% (n = 5) | Mean days until recovery:<br>None, 22.95 days<br>Improve, 26.42 days<br>Persist, 34.94 days | Patients who have vestibular symptoms compared to patients who do not have a significantly longer recovery. |
| Whitney et al[38] | Prospective cohort | An athlete who sustained a concussion while attending a participating institution in the CARE consortium who opted to collect VOMS data. | None disclosed | Age:<br>19 ± 1.2 y<br>Male sex:<br>72% (n = 49)<br>Race:<br>White, 69% (n = 47)<br>African American, 22% (n = 15)<br>Asian, 2% (n = 1)<br>Multiracial, 4% (n = 3)<br>Unknown, 3% (n = 2) | Survival curve for abnormal VOMS predicting recovery (Kaplan-Meier log-rank Chi-square):<br>Smooth pursuits, 4.98, $P = .026$<br>Horizontal saccades, 5.04, $P = .025$<br>Vertical saccades, 4.8, $P = .028$ | In patients who had a 2-point or more symptom increase, the length of recovery was significantly longer than patients who had less than a 2-point symptom increase after the VOMS screening. |

**Table 2. Continued From Previous Page**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| | | | | Sport classification:<br>Contact, 79.4% (n = 54)<br>Limited contact, 16.2% (n = 11)<br>Noncontact, 4.4% (n = 3)<br>ADHD:<br>7% (n = 5)<br>Hx migraines:<br>13% (n = 9) | Convergence, 4.64, $P = .031$<br>Initial VOMS assessment symptoms (mean ±SD, % abnormal test)<br>Smooth pursuits, 7.9 ± 6.2; 81%<br>Horizontal saccades, 8.4 ± 6.6; 82%<br>Vertical saccades, 8.3 ± 6.6; 82%<br>Convergence, 8.3 ± 6.8; 81%<br>VOR-horizontal 8.3 ± 6.7; 83%<br>VOR-vertical 8.4 ± 6.8; 85%<br>Visual motion sensitivity, 8.4 ± 7.3; 82% | Symptom increase of 2 or more on the VOMS was associated with a 3.5-day longer recovery. |

patients ($P = .008$)[39] and Sufrinko et al finding smooth pursuits had the strongest association with recovery over 30 days (odds ratio [OR] = 1.5 [95% CI = 1.19, 1.90], $P < .001$).[32] Although Leddy et al[26] did not find a statistically significant relationship between a positive smooth pursuit at initial examination (1 to 10 days postinjury), upon a second visit (13.6 ± 1 days after visit 1) the authors did find a statistically significant association ($P = .0001$) between a positive smooth pursuit test and longer recovery at the second visit. When comparing saccadic testing and prolonged recovery, Worts et al[39] found that patients who had a higher symptom provocation for either horizontal or vertical saccades were more likely to be in the prolonged recovery group (horizontal saccades: $P = .003$, crude (unadjusted) OR = 2.087 [95% CI = 1.375, 3.167]; vertical saccades: $P = .039$, crude OR = 1.462 [95% CI = 0.983, 2.173]). Similarly, Sufrinko et al[32] found that a positive smooth pursuit was predictive of recovery of 30 to 90 days (OR = 1.5 [95% CI = 1.19, 1.90], $P < .001$) and a positive smooth pursuit, horizontal or vertical saccades was predictive of a recovery of 15 to 29 days (smooth pursuits: OR = 1.25 [95% CI = 1.02, 1.55], $P = .036$; horizontal saccades: OR = 1.31 [95% CI = 1.06, 1.62], $P = .013$; vertical saccade: OR = 1.22 [95% CI = 1.01, 1.47], $P = .035$).

A similar assessment of saccadic functioning, the King-Devick test, was included in 4 studies within this subgroup that dichotomized recovery.[11,28,34,39] Among these studies, only Worts et al[39] found that patients who took longer to complete the King-Devick test were more likely to have a prolonged recovery (total time: $P < .001$; crude OR = 2.984 [95% CI = 1.958, 4.546]). Specifically, patients in the prolonged group took a longer (73.2 ± 21.7 seconds) time to complete the King-Devick test than those in normal recovery (56.9 ± 14.0 seconds).[39] Martinez et al[34] found that patients who had symptom provocation during the test were almost 3 times as likely to have a prolonged recovery (OR = 2.98, $P < .01$). Price et al[11] found a small but nonsignificant effect of 1.09 (95% CI = 0.88, 1.34), demonstrating a potential increased likelihood of prolonged recovery when testing took longer than the 75th percentile for the respective age group on the King-Devick test. In contrast, Cheever et al[28] found no statistically significant difference between performance on the King-Devick test between patients who had a prolonged vs normal recovery at initial visit or any subsequent visit (initial visit: $P = .214$; 2 weeks: $P = .779$; 6 weeks: $P = .698$).

A positive NPC appears to be associated with prolonged concussion recovery, according to 4 studies,[26,29,33,39] which reported statistically significant relationships. Sufrinko et al[32] found a similar result comparing convergence distance predictive of a recovery of 15 to 90 days compared to a recovery of ≤14 days. Cheever et al[28] did not find an association between a positive NPC and the likelihood of prolonged recovery at initial visit ($P = .114$); however, the authors used a shorter elapsed time to dichotomize patients into prolonged and normal recovery, namely, 16 days.

Researchers of four studies[26,30,32,39] examined VOR testing with mixed results. Eagle et al[30] reported a significant relationship between a positive VOR and longer recovery time in both male and female patients. Sufrinko et al[32] found positive horizontal and vertical VOR predictive of longer recovery with reported ORs as high as 1.31 by using the horizontal VOR test to predict a recovery of 30 to 90

**Table 3. Studies Examining Natural Recovery of Vestibular and Oculomotor Screenings**

| Study | Design | Inclusion Criteria | Exclusion Criteria | Group Differences | Outcome Measures | Conclusions |
|---|---|---|---|---|---|---|
| Büttner et al[35] | Prospective longitudinal | Diagnosed with a concussion by emergency department physician. | Sustaining a concussion in the previous 12 months; a history of greater than 3 lifetime concussions; loss of consciousness greater than 1 minute after the current sport-related concussion; a history of vestibular disorder; or any visual abnormality not correctible by lenses | Concussion history:<br>Concussion group, 52% (n = 26)<br>Control group, 36% (n = 18)<br>Learning disability:<br>Concussion group, 12% (n = 6)<br>Control group, 2% (n = 1) | VOMS measures<br>Time to return to activity<br>Symptom severity | The VOMS has a high negative predictive value and may be useful for ruling out concussion soon after injury. |
| Glendon et al[36] | Prospective cohort | Rugby athletes who sustained a concussion during the 2019–2020 season. | None disclosed | Age:<br>All athletes, 20.5 ± 1.5 y<br>SRC, 20.62 ± 3.5 y<br>Male sex:<br>All athletes, 65.7% (n = 92)<br>SRC, 61.4% (n = 25)<br>Previous concussion:<br>All athletes, 75% (n = 90)<br>SRC, 73.8% (n = 31)<br>Learning disability:<br>All athletes, 25% (n = 35)<br>SRC, 14.3% (n = 6) | Wilcoxon sign rank testing (median VOMS score after concussion):<br>2 days, 3.0 (0–20.5), z = −4.375, $P = .000$<br>4 days, 3.0 (0–12.25), z = −4.707, $P = .000$<br>8 days ,0.0 (0–3), $P < 0.005$ | University athlete's symptom burden after concussion returned to near baseline around 8 days postconcussion along with vestibular and oculomotor functioning. |
| Henry et al[25] | Prospective case series | Patients aged 14–22 y and had suffered a SRC within 7 days of initial assessment. | History of special education; history of neurological or psychiatric disorders; previous moderate-to-severe TBI (Glasgow Coma Scale, <13); previous brain surgery; current use of central nervous system-affecting medications; history of 3 or more concussions; or previous concussion within the past 6 months | Mean age, 16.5 ± 1.9 y<br>Male, 64%<br>Sport played:<br>Football, n = 16<br>Soccer, n = 13<br>Hockey, n = 10<br>Softball, n = 6<br>Lacrosse, n = 5<br>Basketball, n = 4<br>Cheer, n = 4<br>Volleyball, n = 3<br>Ski or snowboarding, n = 2<br>Wrestling, n = 2<br>Field hockey, n = 1 | VOMS score:<br>Week 1, 11.0 ± 9.9 (n = 61)<br>Week 2, 5.0 ± 8.1 (n = 63)<br>Week 3, 3.0 ± 7.4 (n = 58)<br>Week 4, 2.1 ± 6.9 (n = 54)<br>$F_{2,73} = 29.26$, $P < .001$, n = 50<br>Dizziness interview score:<br>Week 1, 9.5 ± 8.2 (n = 61)<br>Week 2, 4.6 ± 6.3 (n = 62)<br>Week 3, 2.1 ± 5.5 (n = 56)<br>Week 4, 1.8 ± 5.4 (n = 54)<br>$F_{2,82} = 29.97$, $P < .001$, n = 48 | Dizziness and vestibular-oculomotor symptoms had significantly decreased after 4 weeks compared to 1 week and 2 weeks postconcussion. |

**Table 4. Quality Assessment Results: Studies Comparing Typical and Prolonged Recovery**

| Reference | Study Design | Level of Evidence | Q1: Representative Participants | Q2: Appropriate Measures | Q3: Complete Outcome Data | Q4: Confounders Accounted For | Q5: Intervention Administered as Intended |
|---|---|---|---|---|---|---|---|
| Cheever et al[28] | Prospective cohort | 2 | Yes | Yes | No | Can't tell | Yes |
| DuPrey et al[29] | Case control | 3 | Yes | Yes | Yes | Yes | Yes |
| Eagle et al[30] | Retrospective chart review | 3 | Yes | Yes | Yes | Yes | Yes |
| Ellis et al[27] | Retrospective cross sectional | 3 | Yes | Yes | No | Yes | Yes |
| Knell et al[31] | Prospective case series | 4 | Yes | Yes | Yes | Yes | Yes |
| Leddy et al[26] | Quantitative RCT | 2 | Yes | Yes | No | Yes | Can't tell |
| Martinez et al[34] | Retrospective cohort | 2 | Yes | Yes | Yes | Yes | Yes |
| Price et al[11] | Retrospective cohort | 3 | Yes | Yes | Yes | Can't tell | Yes |
| Sufrinko et al[32] | Cohort study | 2 | Yes | Yes | Yes | Yes | Yes |
| Walker et al[33] | Retrospective cross sectional | 3 | Yes | Yes | Yes | Yes | Yes |
| Worts et al[39] | Retrospective cohort | 3 | Yes | Yes | Yes | Can't tell | Yes |

Abbreviation: RCT, randomized controlled trial.

days compared to a recovery less than 14 days. Interestingly, in the same study, the horizontal and vertical VOR tests were unable to predict a recovery of 15 to 29 days compared to a recovery of less than 14 days when using multinomial regressions.[32] Counter to these results, researchers of 2 studies (Leddy et al[26] and Worts et al[39]) found no statistically significant differences between patients with a prolonged and normal recovery when comparing results of VOR testing. Worts et al[39] did find numerical differences between the prolonged and normal groups on VOR testing, but the differences did not reach statistical significance.

Eagle et al,[30] Sufrinko et al,[32] and Worts et al[39] examined visual motion sensitivity (VMS) with similar findings across studies that a positive VMS is related to prolonged recovery. Eagle et al[30] found a significant relationship between a longer recovery and positive VMS. When Worts et al[39] included extreme test scores in regression models, they found that VMS is likely to predict prolonged recovery with an OR of 1.54 (95% CI = 1.13, 2.09) and a crude OR of 4.36 (95% CI = 2.13, 8.93) for an adjusted OR. Sufrinko et al[32] found in a multinomial regression analysis that a patient with a positive VMS was 1.23 times as likely to have a 30- to 90-day recovery relative to a recovery less than or equal to 14 days.

Finally, researchers of 5 studies[11,27,30,34,39] reported on grouped vestibular and oculomotor testing positivity and its relationship to prolonged recovery. Worts et al[39] found all of the VOMS measures, except VOR, to be predictive of prolonged recovery. Price et al[11] reported a negative VOMS predictive of normal recovery (fully adjusted incidence rate ratio = 1.31 [95% CI = 1.05, 1.63), with a negative predictive value of 80.77%. Eagle et al[30] found that any increase in symptoms during VOMS testing was predictive of a longer recovery in males only, and in females, only the vestibular assessments within the VOMS was predicative of prolonged recovery. Similarly, if a patient did not have a 1-unit increase, researchers found a 90% chance that patients recovered within 30 days.[30] Martinez et al[34] found that patients were 4 times more likely to have a prolonged recovery if they had symptom provocation on any of the screening tests (OR = 4.28, $P < .01$). Additionally, the same study found consistently, across multiple analyses, that a positive vestibular screen was associated with a 3 to 4 times increased odds of delayed recovery in patients after concussion.[34] Ellis et al[27] noted that more than 1 subjective report of vision problems and 1 positive oculomotor or vestibular test were predictive of prolonged recovery (adjusted OR = 4.1 [95% CI = 1.04, 16.16]). A positive oculomotor or vestibular test in the previous study[27] included symptom provocation or an abnormal finding on a singular test. Researchers of these 5 studies demonstrated consistently that the VOMS, vestibular screenings, or oculomotor screenings may help predict recovery.

### Studies Assessing Continuous Time to Recovery After Positive Vestibular or Oculomotor Test

Although many study designs classified patients into normal and prolonged recovery, others chose to use recovery as a continuous variable. Researchers of four studies[37,38,40,41] used continuous days until recovery or return to play. Anzalone et al,[40] Master et al,[41] and Whitney et al[38] reported on smooth pursuits and its relationship to

**Table 5. Quality Assessment Results: Studies Assessing Continuous Recovery After Positive Vestibular or Oculomotor Screening**

| Reference | Study Design | Level of Evidence | Q1: Representative Participants | Q2: Appropriate Measures | Q3: Complete Outcome Data | Q4: Confounders Accounted For | Q5: Intervention Administered as Intended |
|---|---|---|---|---|---|---|---|
| Anzalone et al[40] | Prospective cohort | 2 | Yes | Yes | Can't tell | Can't tell | Yes |
| Glendon et al[36] | Prospective cohort | 3 | Yes | Yes | Yes | Can't tell | Yes |
| Master et al[41] | Retrospective cohort | 3 | Yes | Yes | Yes | Can't tell | Yes |
| Sinnott et al[37] | Prospective Case series | 4 | Yes | Yes | Yes | Can't tell | Yes |
| Whitney et al[38] | Prospective cohort | 2 | Yes | Yes | Yes | Can't tell | Yes |

recovery; all researchers found a significantly longer recovery in patients who had a positive smooth pursuits test than patients who had a negative test. Similarly, a positive saccades was found to be significantly associated with a longer recovery by Whitney et al[38] ($P = .025$) and Anzalone et al[40] (horizontal saccades: $P = .018$, vertical saccades: $P < .001$), a positive VOR was found by Anzalone et al[40] (horizontal VOR: $P = .018$, vertical VOR: $P = .002$) and Master et al[41] (log-rank $P = .001$), and a positive NPC was found by Whitney et al[38] ($P = .031$).

Whitney et al[38] found that patients who had a VOMS symptom increase of greater than or equal to 2 had an average recovery time of 3.5 days longer than those who had a negative VOMS. Knell et al[31] assessed symptom increase within sexes and found that (1) in males, a 1-unit increase in symptom provocation during VOMS assessment increased recovery time by 1.38 days ($P < .001$), and (2) in females, the recovery duration per 1-unit increase was 1.73 days ($P < .001$). Similarly, Price et al[11] reported that patients who had a 2-point increase on any VOMS test had a 1.31-day longer recovery than patients with a lesser increase. Researchers of another study found that patients who reported more than 1 vision problem and at least 1 positive oculomotor or vestibular test had a median recovery time of 40 days (interquartile range = 28.5–54 days) compared to 21 days (interquartile range = 13–32 days) in patients who did not report these symptoms and had negative oculomotor or vestibular tests.[27]

Additionally, Sinnott et al[37] examined recovery among patients who had no vestibular symptoms compared to those who reported their vestibular symptoms were improving over time and patients who indicated their vestibular symptoms were persisting. In patients with improving vestibular symptoms, recovery was 3.47 days longer than patients with no vestibular symptoms. The difference reported by Sinnott et al[37] between patients who had no symptoms and persisting symptoms was even greater with patients experiencing persisting symptoms having a 11.99-day longer recovery than patients with no vestibular symptoms. Researchers of these studies consistently suggest that a longer recovery is associated with positive vestibular or oculomotor tests.

## DISCUSSION

Researchers of 14 of the 19 included studies in this systematic review suggest that patients having a positive vestibular or oculomotor screening test is indicative of longer recovery than patients who do not test positive on these screenings. Authors of these studies consistently found that vestibular or oculomotor tests are able to predict recovery, with authors of studies reporting a difference of slightly more than 1 day.[11] In contrast, other authors report a 3- to 4-day difference in recovery length.[31,37,38] It appears that if patients report vestibular or oculomotor symptoms or screen positive on vestibular or oculomotor testing, they will have a longer recovery than patients who do not because these systems affect how people interact with their environment. Other researchers have found the VOMS to have relatively low false-positive rates[42] and similar impairments between collegiate and high school athletes.[43] Moreover, sideline assessments of oculomotor testing, like the King-Devick test, have been found to be a good supplemental tool to traditional sideline assessment tools, such as

**Table 6. Quality Assessment Results: Studies Examining Natural Recovery of Vestibular and Oculomotor Screenings**

| Reference | Study Design | Level of Evidence | Q1: Representative Participants | Q2: Appropriate Measures | Q3: Complete Outcome Data | Q4: Confounders Accounted For | Q5: Intervention Administered as Intended |
|---|---|---|---|---|---|---|---|
| Büttner et al[35] | Prospective longitudinal | 2 | Yes | Yes | Yes | Can't tell | Yes |
| Glendon et al[36] | Prospective cohort | 3 | Yes | Yes | Yes | Can't tell | Yes |
| Henry et al[25] | Prospective case series | 4 | Yes | Yes | No | Can't tell | Yes |

the SCAT5.[44] Within the broader prognostic indicator literature for concussion, this review builds upon previous literature[12,13] in which authors suggest that vestibular or oculomotor dysfunction may play a role in identifying patients with persisting symptoms who have a longer recovery. As such, the vestibular and oculomotor assessments should be included as part of a multimodal concussion assessment battery.

Our findings should be interpreted in the context of several limitations. Most patients were seen in concussion specialty care; the aggregation of findings suffered from inconsistent methods, including assessment tool and timing; and outcome measures were inconsistent. Within the studies included in the systematic review in which researchers examined VOMS testing, 8 studies (Büttner et al,[35] Eagle et al,[30] Glendon et al,[36] Henry et al,[25] Price et al,[11] Sinnott et al,[37] Whitney et al,[38] and Worts et al[39]) classified a positive VOMS as symptom provocation of greater than 2, as proposed in the original article for VOMS testing by Mucha et al.[21] Authors of 4 articles (Anzalone et al,[40] Leddy et al,[26] Master et al,[41] and Martinez et al[34]) used any symptom provocation as a positive VOMS. This discrepancy makes it difficult to compare studies because of the different operationalizations for which some patients in the latter group of studies would test positive. In the former group, if the symptoms did not reach a threshold greater than 2, the patients would have been noted as negative. The populations studied in the included articles ranged from as young as 5 years old to 40 years old. However, only Büttner et al[35] included athletes who were older than collegiate athletes, and authors of 2 studies (Ellis et al[27] and Walker et al[33]) did not exclude patients younger than 5 years old in their methods. The weighted mean age for studies that reported mean age is 16.4 years old, demonstrating that the patient population is concentrated in high school-aged patients. The adolescent age group appears to sustain an inordinate number of concussions, as supported by epidemiologic research.[45] Having most patients treated in concussion specialty care limits the clinical applicability of this review. Patients who are seen in specialty care often have access to private insurance and are of a higher socioeconomic status, and thus, they are able to seek care earlier, which has also been found to reduce recovery time.[46] Also, our findings may not be generalizable to patients in lower socioeconomic situations. Additionally, patients evaluated in specialty clinics may have had symptoms longer[47] or more severe symptoms than patients who were evaluated by only an athletic trainer or primary care provider. These patients may not represent the larger proportion of patients whose concussions do not require specialty care.

Additionally, the methods of the included studies were varied, and the authors were unable to combine the results of these studies into a meta-analysis. Furthermore, the authors reported a variety of evaluation timepoints, outcomes, and analytical approaches, including VOMS component interpretation, which limited the direct comparison of results across studies (Supplemental Table). Furthermore, recent evidence suggests that using a change score with the VOMS, rather than the total score, may improve the identification of concussion through component and overall clinical cut-offs.[48] Future researchers should use multiple variables in the concussion evaluation to help clinicians predict a prolonged recovery while using the shortest clinical examination.

## CONCLUSIONS

Vestibular and oculomotor screening tests can help inform clinicians about a patient's status. With the findings of this systematic review, we conclude that a positive vestibular or oculomotor assessment may be prognostic of a longer recovery time than a negative screening (Strength of Recommendation: B). Although researchers of most studies found that a positive vestibular or oculomotor screen was associated with a longer recovery, most of the included studies were level 3 or 4 evidence and are not generalizable to patient populations. However, clinicians in all settings should be encouraged to include vestibular or oculomotor assessments into their concussion assessment battery to inform rehabilitative efforts and monitor recovery (Strength of Recommendation: C). These assessments are cost effective, require little to no equipment, and can assist clinicians in determining dysfunction, informing rehabilitative efforts, and aiding in determining a patient's prognosis.

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