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Review of Vestibular and Oculomotor Screening and Concussion Rehabilitation

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Vestibular and oculomotor impairment and symptoms may be associated with worse outcomes after sport-related concussion (SRC), including prolonged recovery. In this review, we evaluate current findings on vestibular and oculomotor impairments as well as treatment approaches after SRC, and we highlight areas in which investigation is needed. Clinical researchers have intimated that recovery from SRC may follow certain clinical profiles that affect the vestibular and oculomotor pathways. Identifying clinical profiles may help to inform better treatment and earlier intervention to reduce recovery time after SRC. As such, screening for and subsequent monitoring of vestibular and oculomotor impairment and symptoms are critical to assessing and informing subsequent referral, treatment, and return to play. However, until recently, no brief-screening vestibular and oculomotor tools were available to evaluate this injury. In response, researchers and clinicians partnered to develop the Vestibular/Ocular-Motor Screening, which assesses pursuits, saccades, vestibular ocular reflex, visual motion sensitivity, and convergence via symptom provocation and measurement of near-point convergence. Other specialized tools, such as the King-Devick test for saccadic eye movements and the Dizziness Handicap Inventory for dizziness, may provide additional information regarding specific impairments and symptoms. Tools such as the Vestibular/Ocular-Motor Screening provide information to guide specialized referrals for additional assessment and targeted rehabilitation. Vestibular rehabilitation and visual-oculomotor therapies involve an active, expose-recover approach to reduce impairment and symptoms. Initial results support the effectiveness of both vestibular and visual-oculomotor therapies, especially those that target specific impairments. However, the evidence supporting rehabilitation strategies for both vestibular and oculomotor impairment and symptoms is limited and involves small sample sizes, combined therapies, nonrandomized treatment groups, and lack of controls. Additional studies on the effectiveness of screening tools and rehabilitation strategies for both vestibular and oculomotor impairment and symptoms after SRC are warranted.

Key Words: assessment, return to play, therapies

An estimated 1.6 to 3.8 million sport-related concussions (SRCs) occur annually in the United States.[1] The SRC has been deemed a significant public health concern by the Centers for Disease Control and Prevention.[2] After an SRC, a patient may present with a variety of physical (eg, headache, dizziness), cognitive (eg, memory, attention), affective (eg, depression, anxiety), and sleep-related symptoms and impairments.[3] Among the least understood but potentially important of these symptoms and impairments are vestibular and oculomotor disturbances. Vestibular symptoms may include dizziness, nausea, vertigo, blurred or unstable vision, and discomfort in busy environments.[4] Oculomotor symptoms may include blurred vision, convergence insufficiency, difficulty reading, diplopia, headaches, difficulty tracking a moving target, general asthenopia (eye strain), dizziness, nausea, and problems scanning for visual information.[5] From a functional perspective, oculomotor impairment and symptoms may result in difficulty reading, impaired academic performance, and related cognitive impairments.[5] Because they may be demonstrated by poor performance on such tasks as computer work, reading comprehension, and word and phrase recognition,[5] these functional impairments may be misattributed to a cognitive deficit after SRC instead of an oculomotor problem. Consequently, many athletes do not receive effective treatment for these symptoms and impairments, leading to unnecessarily prolonged morbidity after SRC. We will evaluate current research on vestibular and oculomotor impairments and treatment approaches after SRC and highlight areas in which research is deficient.

Many vestibular and oculomotor symptoms are evident only when provoked by stimuli or movements.[6] Therefore, vestibular symptoms may be exacerbated by busy environments, such as a shopping mall or crowded school hallway, and quick head movements, such as those involved in dynamic sports. Similarly, oculomotor symptoms may worsen during activities such as reading or taking notes in a classroom. Vestibular and oculomotor impairments and symptoms occur in approximately 60% of athletes after an SRC.[7]

Vestibular and oculomotor impairment and symptoms may be associated with worse outcomes in both the acute (<1 week) and subacute (1 week–3 months) time periods after SRC.[8,9] In fact, Lau et al[9] reported that dizziness at the time of injury in more than 100 high school football players was associated with a 6-fold increase in protracted recovery (>21 days). Corwin et al[8] observed that patients with vestibular insufficiency at their first clinical visit were more likely to exhibit protracted recovery. Specifically, abnormalities on vestibular-ocular reflex (VOR) testing or tandem-gait performance resulted in an average recovery time of 59 days versus just 6 days for those without vestibular abnormalities. Furthermore, those who experienced vestibular difficulties scored significantly lower on verbal memory, processing speed, and reaction time compared with patients who exhibited no vestibular impairments. The majority of injuries reported by Corwin et al[8] (77%) were sport related.

With regard to oculomotor impairment and symptoms, approximately 45% of athletes experienced abnormal near-point convergence distances indicative of convergence insufficiency (CI).[7] In a recent study of CI after SRC in athletes aged 9 to 24 years, researchers[10] observed that athletes with CI experienced more cognitive impairment and SRC-related symptoms after injury than those without CI. Investigators[11] have also suggested that oculomotor impairments may prolong recovery after SRC by reducing the effectiveness of certain interventions, including cognitive rehabilitation.

Lately, clinical researchers[12–14] have intimated that recovery from SRC may follow certain clinical profiles that involve both vestibular and oculomotor pathways in addition to cognitive, posttraumatic migraine, anxiety and mood, and cervical disturbances. Although clinical profiles often partially overlap (eg, vestibular impairment with posttraumatic migraine, cognitive impairment with oculomotor symptoms), distinct impairments and symptoms are often apparent. For example, investigators[15] have reported oculomotor dysfunction in visuospatial and visual attention stemming from subcortical brain involvement, in addition to other cognitive impairments. As such, comprehensive assessments of multiple domains are warranted to determine the presence of specific clinical profiles and the contribution of multiple profiles. Even though it has been suggested[16] that vestibular and oculomotor clinical profiles are associated with more pronounced impairment and longer recovery, these clinical profiles may be more amenable to active rehabilitation approaches. Therefore, assessing and treating these domains is critical to informing better clinical care for athletes after SRC. However, it is important to understand the underlying systems involved in these impairments and symptoms in order to better conceptualize clinical care.

DISRUPTION OF THE VESTIBULAR AND OCUOLOMOTOR SYSTEMS AFTER SRC

The vestibular system is a complex structure that detects motion of the head in time and space, thus relaying a subjective sense of self-motion.[17] The 2 primary functional aspects of the vestibular system are the vestibulospinal component (which helps to regulate postural stability) and the vestibulo-ocular component (which integrates vision and movement of the head). Together, these components of the vestibular system play a vital role in balance, gaze stabilization, and visual and spatial orientation. Disruptions to this system, such as after SRC, can result in symptoms and impairment in balance, gait, and vision.[8] Specifically, the vestibular system allows the eyes to remain fixed on a target while the head and body move.[18] Sensory input from the inner ear allows for adjustments in eye movements and motor control that stabilize the head and body during movement. This system involves the vestibular apparatus, sensory organs, and central processing and coordination in the brain. Specific areas of the brain, such as the cerebellum, cerebral cortex, thalamus, reticular formation, and brainstem, are responsible for integrating sensory information from the vestibular apparatus and sensory organs to allow an athlete to move and orient body position to space and time.[4] An SRC that affects any of these brain areas may interfere with this process and result in symptoms including imbalance, vertigo, and dizziness. Vestibular alterations may be a common phenomenon after SRC: 50% to 80% of patients experience dizziness.[8,19,20]

Oculomotor function occurs via versional eye movements (ie, pursuits and saccades) and vergence eye movements (ie, convergence and divergence), which combine with visual-fixation movements (eg, gaze holding, optokinetic responses, VOR) to change the angle of gaze and hold visual images steady.[21,22] These movements work in conjunction with the optokinetic and vestibular systems to maintain visual stability and scanning capabilities. The underlying pathophysiology of oculomotor dysfunction after SRC is complex, involving disrupted function in the midbrain, cerebellum, pons, and multiple regions of the cerebral cortex.[23–27] After SRC, oculomotor dysfunction can result in problems with eye movement control, which may affect the ability to perform dynamic eye movements and keep visual targets stationary. These oculomotor dysfunctions may manifest as symptoms including blurriness, oscillation (ie, jumping) of objects in the visual field, or even dizziness.[16]

In addition, vestibular and oculomotor dysfunction may lead to visual motion sensitivity. *Visual motion sensitivity* refers to a heightened awareness of normal visual stimuli due to an inability to centrally integrate visual and vestibular information. Patients with visual motion sensitivity often experience dizziness, vertigo, nausea, or disequilibrium in busy environments such as shopping malls or grocery stores.[16] These symptoms and dysfunction may be accompanied by anxiety after SRC; however, research is needed to determine how prevalent anxiety is in this situation.

SCREENING FOR VESTIBULAR AND OCULOMOTOR IMPAIRMENT AND SYMPTOMS

Given the high prevalence of vestibular symptoms after SRC[8,19,20] and the relationship between these vestibular symptoms and protracted recovery,[1,8] the vestibular and oculomotor systems should be screened after SRC and continually monitored during recovery. There has been an unmet need for a screening tool to identify these types of impairments and symptoms after SRC. As with any screening tool, the keys to success for a vestibular and oculomotor impairment and symptoms screening tool include brevity, validity, and reliability. With these keys in mind, clinicians and researchers collaborated to develop the Vestibular/Ocular-Motor Screening (VOMS) tool.[7] The VOMS was designed to be a brief clinical screening tool used in conjunction with other assessments (eg, neurocognitive, symptoms, balance) and a comprehensive clinical examination, interview, and medical history.

Traditionally, clinical balance measures have been used to assess vestibular function after SRC. Among the most common is the Balance Error Scoring System. Clinical balance tests, although effective in assessing vestibulospinal impairment, do not address many of the dynamic aspects of the vestibular system, including the vestibulo-ocular component. Also, as previously noted, dizziness may result from inadequate integration of the vestibular and ocular systems, requiring a more comprehensive measure to capture the insufficiencies present after SRC.[13]

The VOMS tool measures symptom provocation after each assessment of 5 domains: smooth pursuit, horizontal and vertical saccades, convergence, horizontal and vertical VOR, and visual motion sensitivity. Convergence is assessed based on the average measurement of 3 trials of near-point convergence distance (centimeters). Before the assessment, patients are instructed to rate symptoms of headache, dizziness, nausea, and fogginess on a scale ranging from 0 to 10, with 0 meaning *no symptoms at present*. After each assessment, patients are asked to reevaluate their symptoms, paying specific attention to how their symptoms may have changed.[7] The VOMS tool has demonstrated strong internal consistency and significant correlation with the Post-Concussion Symptom Scale as well as the ability to potentially differentiate concussed participants from healthy controls[7]; however, more research is warranted on its use as an appropriate screening tool for vestibular symptoms after SRC. Using a screening tool such as the VOMS may allow for interventions (eg, vestibular rehabilitation) to aid in recovery after SRC.

Screening tools that include a breadth of vestibular and oculomotor assessments, such as the VOMS, provide an overview of potential impairments and symptoms that require more in-depth assessment and potential referrals for treatment. However, screening tools that offer more specific information regarding a particular vestibular or oculomotor impairment or symptom may help to identify the source of the aberrant signal after SRC. For example, it is important to assess dizziness in depth after an SRC, as it can have multiple causes that would indicate the need for specific interventions. The dizziness could be related to migraine or cervicogenic, psychiatric, or vestibular dysfunction.[9] Dizziness that represents impaired function and integration of the vestibular and oculomotor systems is amenable to vestibular and oculomotor rehabilitation strategies.[13] One screening tool that has been effective in delineating dizziness after SRC is the Dizziness Handicap Inventory. This 25-item self-report questionnaire assesses the functional, physical, and emotional effects of dizziness during the previous month. A score greater than 10 indicates that a referral is needed. The inventory takes approximately 10 minutes to complete and can provide additional information regarding the cause of the dizziness, which will facilitate better treatment and rehabilitation for athletes with dizziness after SRC. In addition, serial assessments using the Dizziness Handicap Inventory help clinicians quantify recovery for athletes with a vestibular clinical profile after SRC. Moreover, this type of assessment is useful in determining the effectiveness of vestibular rehabilitation after SRC; patients who underwent vestibular rehabilitation demonstrated improved measures of gait and balance as well as self-reported improvements in dizziness and balance confidence.[28]

It is important to note that other brief assessments, such as the King-Devick test, have previously attempted to assess isolated oculomotor dysfunction by measuring saccadic eye movements.[29] These types of tests provide a brief and valid measure of saccadic eye movements under a fixed test condition.[30,31] However, they do not measure oculomotor function, such as pursuits, convergence, and accommodation, and therefore may be limited in their screening capability.[13]

The King-Devick test consists of a series of 4 cards: 1 practice card followed by 3 test cards. Each card has 8 rows of 5 single-digit numbers. Participants are asked to read the numbers aloud quickly and accurately, and the time and number of errors are compared with either age-matched norms[29] or baseline performance.[30,31] Researchers[30,31] have demonstrated that the King-Devick test can identify an SRC when a patient's symptom scores do not necessarily reflect impairment. However, previous investigators[29] observed that the King-Devick test is highly susceptible to practice effects, noting performance improvement with subsequent test administrations. In addition, the King-Devick test does not include an assessment of symptom provocation, which may enhance its utility after SRC.

The King-Devick test has been compared with other SRC assessment tools, such as the Sport Concussion Assessment Tool 2 (SCAT2), Standardized Assessment of Concussion, Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), and Post-Concussion Symptom Scale.[32,33] In concussed adolescent athletes, King-Devick times were associated with scores on the Post-Concussion Symptom Scale and visual motor speed and reaction time scores on ImPACT.[33] Galetta et al[32] observed an association between the King-Devick score and the Standardized Assessment of Concussion immediate memory score in baseline testing of professional ice hockey players. In conclusion, although the King-Devick test provides an objective measure of timed saccadic eye movements after SRC that may reflect impairment in this subdomain, it is limited as a measure of only 1 component of oculomotor impairment and does not include any vestibular components.

VESTIBULAR AND OCULOMOTOR REHABILITATION AFTER SRC

After SRC, if a vestibular or oculomotor clinical profile is identified, targeted rehabilitation strategies should be implemented to reduce impairment and symptoms and expedite recovery. Rehabilitation strategies should be based on a targeted approach that matches therapies to the specific clinical profile.[13,14,16] In addition, unlike conventional rest-based therapies for SRC that are passive in nature, therapies for vestibular and oculomotor impairment and symptoms are active, including vestibular and oculomotor protocols.[13] In short, these therapies are based on an expose-recover model involving exercises that target and stress specific impairments and symptoms in a controlled way to promote recovery. Symptom provocation is used as a marker for tolerance of specific exercises, and some level of symptom provocation is necessary to promote recovery. However, in contrast to the aerobic-based expose-recover models used by Leddy et al,[34] the approach for athletes with vestibular and oculomotor clinical profiles focuses on dynamic movements, in particular those involving the head and eyes.

Vestibular Rehabilitation Strategies

After SRC, different vestibular rehabilitation techniques may be used based on the symptoms and impairments present. Commonly, vestibular impairments such as benign paroxysmal positional vertigo,[35] VOR impairment,[36] visual motion sensitivity,[37] balance dysfunction,[18] and cervicogenic dizziness[38,39] are noted after SRC.[16] A clinician with specialized training in vestibular rehabilitation should perform the necessary interventions. Impairment of the VOR can be improved by targeted gaze-stability training. *Gaze stability* refers to the ability to hold the eyes on a fixed location while the head is in motion. Gaze-stability training requires a patient to maintain visual focus while moving his or her head and can be used in a variety of conditions to facilitate recovery from VOR impairment. For dysfunction in visual motion sensitivity, graded and systematic exposure to visually stimulating environments is often used as a rehabilitative technique to habituate the individual. Balance training and rehabilitation strategies, including sensory organization training, divided attention training, and dynamic balance training, may be used to treat impaired postural control. Treatment of cervicogenic dizziness after SRC includes manual therapy techniques for underlying cervical dysfunction combined with oculomotor and sensorimotor retraining. Finally, dizziness due to benign paroxysmal positional vertigo can be evaluated and treated using canalith-repositioning maneuvers performed by a vestibular physical therapist.[16]

Vestibular rehabilitation may help reduce dizziness and improve balance after SRC.[28] In a retrospective chart review of 114 patients (67 children, 47 adults), Alsalaheen et al[28] explored the effect of vestibular rehabilitation on reducing dizziness after SRC. Those patients who returned for at least 1 session of vestibular rehabilitation demonstrated improved gait and balance, as well as self-reported improvements in dizziness and balance confidence.[28] The results suggest that vestibular rehabilitation may be beneficial for those suffering from dizziness and balance insufficiency after SRC.

Further supporting the role of vestibular rehabilitation, Schneider et al,[40] in a randomized controlled trial, demonstrated that cervicovestibular rehabilitation was effective in reducing time to medical clearance after a concussion. After concussion, patients were assigned to either the control group or the intervention group. Both groups underwent weekly sessions with a physiotherapist, postural education, range-of-motion exercises, and cognitive and physical rest followed by a graded exercise protocol; however, the intervention group also received cervical spine and vestibular rehabilitation. More participants in the intervention group than the control group (73% versus 7%) were medically cleared within the 8-week study period, thus indicating that cervicovestibular rehabilitation may reduce time to medical clearance in those with persistent dizziness or head or neck pain after concussion.[40]

Currently, research exploring vestibular rehabilitation is still in its infancy. Although the preliminary findings are promising and suggest that vestibular therapy may be beneficial for treating vestibular impairments after SRC, more work in this area is warranted. The 2 studies[12,33] published on vestibular rehabilitation have their limitations but open the door to furthering our understanding of the role of vestibular treatment after SRC.

Oculomotor Rehabilitation Strategies

Oculomotor impairments may be mitigated through the use of vision therapy. Among the oculomotor problems that can be amenable to vision therapy are convergence and accommodative insufficiency, versional dysfunction, and ocular misalignment.[5] However, clinicians may misidentify oculomotor impairments and symptoms as cognitive problems after SRC. Therefore, a comprehensive screening for oculomotor impairments and symptoms is needed to identify candidates for vision therapy. Once an oculomotor clinical profile is confirmed through screening and appropriate follow-up referrals with an optometrist or ophthalmologist with expertise in concussion care, vision exercises can be implemented. Among the more commonly used exercises to treat athletes with an oculomotor clinical profile after SRC are speeded saccadic eye movements, visual pursuit and tracking tasks, alternating monocular and binocular tasks, and reading tasks. In addition, visual-attention tasks such as visual-field scanning, attentional grid, and near-far–vision focal shifting may also be used. Often these tasks involve the use of prisms, special optical lenses, eye cover-ups, penlights, and mirrors. This equipment is frequently available only through licensed optometrists and ophthalmologists. Consequently, specialized software programs, such as Home Therapy Solutions vision therapy, and mobile applications, such as the Oculomotor Therapy Program, have been developed for in-office therapy, in-home therapy, and remote monitoring of compliance. However, despite anecdotal evidence, the effectiveness of these systems for athletes with SRC has not been empirically substantiated. In spite of this need for additional research regarding their efficacy, in-home approaches offer athletes a more convenient and readily accessible method for vision therapy after SRC.

Overall, empirical evidence is limited for the effectiveness of the vision therapies described earlier. To date, only 2 groups[12,33] have published studies that empirically examined the effectiveness of vision therapy after concussion, and neither focused on an SRC-specific population. Preliminary evidence from these studies suggests that combined oculomotor therapies that target multiple impairments, including convergence and accommodative insufficiency and versional problems, may be effective in reducing symptoms and impairment and improving reading.[41,42] Specifically, Ciuffreda et al[41] noted that the majority (90%) of patients with concussion who completed a vision-therapy program improved in reported symptoms and perceived reading performance. In a very small study ($n = 12$), Thiagarajan et al[42] indicated that combined vision-therapy exercises resulted in targeted improvements in convergence, accommodation, and saccadic eye movements. However, given the reliance on self-reported symptoms in the first study and the small sample sizes, nonrandom group assignments, and focus on nonathletic populations in both studies, these findings need to be interpreted cautiously regarding their application in athletes after SRC. Although more research is needed, these findings provide some evidence for the effectiveness of vision therapy as a treatment for athletes with an oculomotor clinical profile after SRC.

CONCLUSIONS

Vestibular and oculomotor impairments are common after SRC and are associated with prolonged recovery. Therefore, it is critical to screen for vestibular and oculomotor impairments and symptoms in all patients with a suspected SRC. Additionally, vestibular and oculomotor screening may help to augment current treatment approaches for non-SRCs in other settings, such as emergency departments and military environments. Recently, researchers and clinicians have partnered to develop the VOMS, a brief screening tool used to determine if more in-depth vestibular and oculomotor assessment and follow-up therapies are warranted. The VOMS may also be useful in tracking recovery from these impairments and symptoms. Additional study of the VOMS and similar measures is needed. It is important to note that any approach to assessing SRC should be comprehensive and multimodal, incorporating not only vestibular and oculomotor screening but also a comprehensive clinical interview and medical history and neurocognitive, balance, and other assessments.[13] Once vestibular or oculomotor (or both) impairments and symptoms have been identified, clinicians trained in vestibular and vision therapy should initiate appropriate interventions. Preliminary evidence indicates that targeted vestibular and oculomotor therapies may be effective in patients with SRC. However, well-designed, prospective studies of these targeted therapies are needed to determine the best approaches to actively treating patients who experience vestibular or oculomotor impairments and symptoms after SRC. Furthermore, research is warranted to determine the best approaches to screening for and treating vestibular or oculomotor impairments in other populations, including nonathletes.

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