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REVIEW

Vestibular and balance issues following sport-related concussion

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Abstract

Primary objective: To review relevant literature regarding the effect of concussion on vestibular function, impairments, assessments and management strategies.
Reasoning: Dizziness and balance impairments are common following sport-related concussion. Recommendations regarding the management of sport-related concussion suggest including tests of balance within the multifactorial assessment paradigm for concussive injuries.
Analysis: The literature was searched for guidelines and original studies related to vestibular impairments following concussion, oculomotor and balance assessments and treatment or rehabilitation of vestibular impairments. The databases searched included Medline, CINAHL, Sport Discus and the Cochrane Database of Systematic Reviews through October 2013.
Main outcomes and results: Dizziness following concussion occurs in ∼67–77% of cases and has been implicated as a risk factor for a prolonged recovery. Balance impairments also occur after concussion and last 3–10 days post-injury. Assessments of balance can be done using both clinical and instrumented measures with success. Vestibular rehabilitation has been shown to improve outcomes in patients with vestibular impairments, with one study demonstrating success in decreasing symptoms and increasing function following concussion.
Conclusions: Best practices suggest that the assessment of vestibular function through cranial nerve, oculomotor and balance assessments are an important aspect of concussion management. Future studies should evaluate the effectiveness of vestibular rehabilitation for improving patient outcomes.

Keywords

Concussion, postural control, rehabilitation

History

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Introduction

Balance, spatial orientation and stable vision are important components of physical activity and athletic participation. The vestibular system plays an integral role in controlling each of these areas and can be negatively impacted by concussion [1–4]. Vestibular function includes both sensory and motor systems and is involved in several different roles related to postural control or balance, including stabilization of the head, controlling the centre of mass, sensing and perceiving motion and maintaining orientation to vertical [5, 6].

The peripheral vestibular system consists of three semicircular canals which are responsible for detecting angular (rotational) acceleration of the head and two otolithic or macular structures which detect linear (translational) movement, as well as the force exerted upon the body by gravity [7]. These structures, in conjunction with the organ of hearing (the cochlea), make up the labyrinth of the inner ear and are housed within the petrous portion of the temporal bone. The three semicircular canals (anterior, posterior and lateral) are arranged approximately orthogonal to each other such that each canal corresponds to movement within a different plane in three-dimensional space (pitch, yaw and roll). The semicircular canals contain a fluid called endolymph and tiny hair cells which act as motion sensors capable of converting mechanical movement into electrical impulses. The canals possess a complimentary push–pull relationship with the labyrinth on the opposite side of the head such that if one side is stimulated in its neural activity the opposite side is inhibited [6, 7]. The otolithic or macular organs are made up of tiny hair cells embedded within a gelatinous membrane and superimposed by calcium carbonate particles known as otoconia. Otoconia are often referred to informally as 'ear rocks' or 'ear crystals' and, when displaced from their anatomic origins, can result in a condition called benign positional vertigo or BPPV (discussed below). There are two distinct otolithic structures, the saccule and the utricle. The saccule is oriented in the sagittal plane of the head, making it more responsive to vertical acceleration (including gravity), whereas the utricle, being more horizontally positioned, is more responsive to side-to-side and centripetal acceleration [8].

Each of the sensory structures within the vestibular system gather information about different types of movement and then transduce this information into nerve impulses which are sent to the brainstem nuclei to elicit a corresponding motor response. A combination of vestibular reflexes participate in the response including: the vestibulo-ocular reflex (VOR), the

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vestibulospinal reflex (VSR) and the vestibulocollic reflex (VCR). The vestibulo-ocular reflex (VOR) serves to maintain stable vision during movement of the head and is regulated by the semicircular canals (angular VOR) and otilithic organs (linear VOR) [9]. The angular VOR is responsible for gaze stabilization during head rotation and the linear VOR compensates for non-angular head movements, taking into account the distance of the object being viewed. The vestibulospinal reflex (VSR) is important in stabilizing the body to maintain posture, keeping the centre of mass over the base of support. The VSR is an upper and lower limb response which extends the limbs ipsilateral to the direction of acceleration and contracts the limbs in the direction contralateral to acceleration [10]. Lastly, the vestibulocollic reflex (VCR) acts on the muscles of the neck to stabilize the head. The VCR, although not as well understood, is often thought of as synonomous to a righting reflex, fixing the head position in a horizontal gaze orientation relative to that of gravity and independent of body movement [11, 12]. Collectively, these reflexes support maintenance of equilibrium by stabilizing vision and body position when the head is set into motion.

Vestibular dysfunction can occur from a variety of illnesses and injuries, including traumatic brain injury (TBI) or concussion [1–4]. The mechanism of injury that results in a TBI can also cause direct injury to the vestibular organs, the vestibular nerve or result in a disruption of brainstem, visual, motor or ocular pathways. In addition to the direct impact of the TBI on vestibular function, concomitant vestibular pathologies can result (Table I), which should be evaluated for and treated accordingly along with the concussion.

Vestibular impairments following concussion

Following mTBI, patients can present with dizziness, balance impairments, vestibular pathology and deficits in cranial nerve function. Although rare, documented in less than 10% of athletes with concussion [13], abnormal cranial nerve assessment is an indicator of more severe trauma and should warrant an immediate referral [14, 15]. Furthermore, the assessment of oculomotor function is an important part of the neurological examination and vestibular assessment to determine whether any associated conditions are present.

Dizziness is the second most commonly reported concussion-related symptom following headache. Studies of high school and college athletes have shown that 67–77% of athletes' self-report dizziness after the concussion [16–19]. In a study of mTBI outside of sport, dizziness was identified as one of the five most common complaints that distinguish post-concussive patients from healthy controls [20]. Additionally, other self-report symptoms, including tinnitus, lightheadedness, blurred vision and/or photophobia often accompany concussion and relate to one of the three sensory systems (visual, vestibular, somatosensory) and may affect the patient's perception of sensory cues, thus resulting in dizziness or feelings of imbalance [21–25].

More recent evidence has suggested that an initial presentation of dizziness is one predictor of a protracted recovery following sport-related concussion [26]. These findings are similar to work done with non-athlete patients that found those with mild or moderate TBI *with* dizziness (66.7% of sample) were more anxious, had higher reports of depression, higher scores on outcomes identifying psychosocial dysfunction and were less likely to return to work [20]. The authors suggested that dizziness is an adverse prognostic indicator and one that should be assessed with the goal of treating the underlying cause as a means to aid recovery post-TBI. Lastly, Kontos et al. [27] identified a revised factor structure for sport-related concussion symptoms, in which dizziness and balance problems clustered into a vestibular–somatic factor at baseline, along with headache, nausea and vomiting. Interestingly, in the post-concussion analysis, dizziness and balance problems loaded across multiple factors, suggesting these complaints could be related to several factors, therefore being important symptoms to

Table I. Summary of vestibular impairments associated with mTBI.

Condition	Location	Assessment possibilities	Suggested treatment
Labyrinthine concussion	peripheral	Nystagmus, unilateral vestibular loss on ENG/VNG study, abnormal VOR (head thrust)	VRT
Benign paroxysmal positional vertigo	peripheral	Paroxysmal nystagmus with head positioning (i.e. positive Dix-Hallpike or Head Roll maneouvre)	Canalith repositioning maneouvre
Post-traumatic Meniere's disease	peripheral	Unilateral hearing loss (specifically low frequencies), nystagmus, unilateral vestibular loss on ENG/VNG study, abnormal electro-cochleography study	Medication, VRT, surgery, other
Perilymphatic fistula	peripheral	Unilateral hearing loss, nystagmus, unilateral vestibular loss on ENG/VNG study, dizziness and/or nystagmus with Valsalva maneouvre	Counselling, surgery
Superior canal dehiscence	peripheral	Unilateral low frequency conductive hearing loss, hyperacusis, sound induced dizziness or nystagmus (Tullio phenomenon), abnormal VEMP study	Counselling, surgery
Post-traumatic migraine	central	Ocular motility abnormalities, nystagmus	Counselling, medication, VRT
Brainstem concussion or other central disorder	central	Ocular motility abnormalities, abnormal SOT	Counselling, medication, VRT

ENG, Electronystagmography; SOT, Sensory Organization Test; VEMP, Vestibular evoked myogenic potential; VNG, Videonystagmography; VOR, Vestibular ocular reflex; VRT, vestibular rehabilitation therapy.

identify after the injury. Collectively, these studies provide some evidence that the initial presence of dizziness is an important clinical finding and one that should be evaluated further.

While dizziness alone may be prevalent following concussion and suggest a protracted recovery, it is often accompanied by balance impairments that can be evaluated through self-report scales or more objectively with clinical and computerized balance assessments. Deficits in balance ability have been reported in patients with concussion [17, 28–33], often as a result of changes in the normal weighing and integration of sensory cues, resulting in postural instabilities. Following sport-related concussion, postural instability has been studied most often in collegiate athletes, with transient impairments in balance lasting between 3–10 days post-injury [25, 28, 29, 33, 34] and one study [17] reporting that 28.6% of concussed athletes had a positive Romberg test. In a meta-analysis of sport concussion studies, Broglio and Puetz [32] reported a large effect of concussion on measures of postural control in the immediate days post-injury ($\Delta = -2.56$) and at a follow-up within the 2 weeks post-concussion ($\Delta = -1.16$), suggesting that identified postural control deficits can exist up to 2 weeks post-injury.

Studies using more sophisticated measures of postural control have been able to identify deficits in the individual sensory systems that contribute to balance. Guskiewicz et al. [28] evaluated the postural stability of high school and collegiate athletes, noting deficits in composite scores through day 3, with recovery to baseline scores occurring between days 3–5 post-injury. When the sensory systems were isolated, patients with concussions demonstrated even more impairments when inaccurate somatosensory cues were present (foam pad or moving surface). Subsequent studies using the Sensory Organization Test have reported deficits in the composite balance score [25, 35, 36] and significantly lower visual [25, 35] and vestibular [25, 36] ratios suggesting that that the overall balance impairments are most likely the result of the inability to resolve sensory conflict coming from unstable surfaces or the absence or inaccurate information provided by visual cues.

Assessment of vestibular function

Vestibular function can be evaluated a number of different ways, each with specific equipment requirements and protocols for testing. Routine vestibular assessment generally includes an evaluation of oculomotor function, static & dynamic positioning, postural control ability, gait, peripheral end-organ stimulation (either via caloric irrigation or rotational paradigm) and self-report outcomes assessment. The indication for each aspect of the vestibular evaluation depends upon the timing of the assessment (on-field vs office), clinical presentation and resources available.

Oculomotor evaluation

The assessment of oculomotor function is an important part of the initial clinical examination for a patient with a concussion. It should be conducted as part of the neurological examination to rule out cranial nerve pathology (Table II) and more severe brain injury. Table III highlights the key features of the oculomotor clinical examination.

Recently, there has been a trend towards objective measures for concussion assessment. In the area of oculomotor function, the King-Devick test has been developed and used as a measure of saccadic eye movement, attention and processing speed [37, 38]. The test is a timed test of rapid number naming in which the patient reads aloud a string of numbers on three test cards. Each test card increases in difficulty with directing lines removed and the numbers placed closer together further challenging the patient. The patient is instructed to read the numbers as fast as they are able without error and the test is scored as the summed time of the three test cards and the number of errors made [37]. Studies in mixed martial arts fighters/boxers [38] and collegiate athletes [37] have demonstrated slower times in

Table II. Cranial nerve clinical presentation and assessment for vestibular function.

Cranial nerve	Clinical presentation	Assessment
II. Optic	Altered visual acuity and/or visual fields	Visual acuity, visual fields, pupillary reactivity Ophthalmoscope exam
III. Oculomotor	Lack of accommodation Dilated/fixed pupils Divergent strabismus Diplopia Eye only moving laterally (difficulty moving up, down or medial)	Tracking in six cardinal positions Convergence on near targets Pursuits Saccades Pupillary reaction Eyelid elevation
IV. Trochlear	Diplopia, affected eye rotated out with inability to turn eye in and down Compensatory head tilt away from affected side	Adduction with downward gaze
VI. Abducens	Impaired ability to turn affected eye outward Affected eye turns inward when looking straight ahead Diplopia with looking towards affected side	Eye movement in horizontal plane looking for deficiencies in lateral gaze
VIII. Vestibulocochlear	Hearing loss Vertigo Nystagmus Impaired balance	Hearing Tympanic membrane examination Eye movement for Nystagmus Postural responses

Table III. A summary of oculomotor assessments for concussion.

Assessment	Purpose	Procedures	Evaluation
Observation	Eye position	Evaluate position of the eye in each orbit in relation to the other Assess range of ocular movements by moving an object in all gaze directions and instruct patient to follow	Evaluate for symmetry in position and movement, strabismus and nystagmus
Smooth pursuits	Slow eye tracking	Instruct patient to follow a slow moving object such as the tip of a pen held ~1 metre from eyes Move the target at a low uniform speed Assess in horizontal, vertical and diagonal planes ~30°	Evaluate for ability to follow target at appropriate speed, look for smooth movements and corrective saccades
Saccades	Quick eye movements	Instruct patient to fixate on two targets alternatively, shifting eyes quickly between the targets Assess in horizontal, vertical and diagonal planes	Evaluate for normal velocity, accurate target acquisition, symmetrical eye movement
Convergence	Assess ability to focus on an object	Have the patient hold an object arm's length away from their eyes and bring in towards their nose stopping when the patient reports double vision	Normal convergence is ~6 cm from the tip of the nose
Dynamic visual acuity	Assesses the VOR	With the use of a Snellen chart, instruct the patient to read the lowest line that they can while the head is stationary The clinician then moves the head at ~1–2 Hz while the patient is instructed to read the lines from the top down, stopping when they cannot read further	Determine the difference in the number of lines the patient can read during the dynamic condition from the static condition If greater than 2 lines, it is indicative of a bilateral vestibular issue

VOR, Vestibular Ocular Reflex; Hz, Hertz.

patients with head trauma compared to those without head trauma or to a pre-season baseline test.

Postural control assessment

Balance assessment can be accomplished using a variety of techniques and tools capable of quantifying or qualifying different characteristics of balance [39, 40]. Balance can be assessed under static conditions, dynamic conditions (e.g. unstable surface, moving platform) or during more functional tasks (Table IV). Furthermore, some assessments require sophisticated equipment while others are more feasible for use in the non-clinical setting. The sections below describe some of the postural control assessments commonly used in concussed patients and reported on in scientific publications. In addition, newer postural control applications using mobile technology are now emerging for assessing sport-related concussions. Many of these technologies have yet to be published in the scientific literature. It is important for clinicians to choose a balance measure that is feasible in their setting and that those administering the assessment are properly trained.

Sensory organization test

The SOT is an instrumented balance assessment that measures the patient's ability to maintain a quiet stance, while altering the sensory cues available to them for maintenance of equilibrium. The SOT consists of six different conditions, with the patient completing three trials for each condition. The SOT includes three different visual scenarios (eyes open, eyes closed, sway referenced) and two different surface scenarios (fixed, sway referenced) [41]. During sway reference support surface conditions, the force plate tilts synchronously with the patient's anterior–posterior centre of gravity sway and, during the sway referenced visual surround conditions, the visual surround tilts synchronously with anterior–posterior centre of gravity sway. The use of the sway referenced surface and surround conditions evaluates the patients' ability to ignore the inaccurate information from the sway referenced senses and appropriately maintain balance. Following the six conditions, an overall composite equilibrium score is calculated and compared against age-matched normative data, with higher scores representing better balance performance. In addition, somatosensory, visual and vestibular ratios can also be derived to determine if sensory integration problems are present that are impairing balance.

Clinical test of sensory interaction on balance

The Clinical Test of Sensory Interaction and Balance (CTSIB) has been used to assess balance using various combinations of visual and support surfaces during static standing [42]. The sequence of test conditions systematically remove or provide inaccurate sensory input from one or more of the three sensory systems through the use of three visual conditions (normal vision cues, absent visual cues, inaccurate visual cues) and two surfaces (stable, inaccurate [unstable] somatosensory cues). The CTSIB can be performed on a force platform with sway measures recorded [28] or scored through a subjective sway assessment using a numeric sway rating (1 = minimal, 4 = fall), recording of stance time in seconds or by measuring body displacement through the use of posture grids or plumb lines [42].

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Table IV. A summary of balance assessments for concussion.

Assessment	Characteristics	Format	Advantages	Disadvantages	Populations studied
Balance Error Scoring System (BESS)	Clinical - Static	Six 20-second balance assessments on firm and foam surface; Eyes closed; Score the number of errors	Easy to administer; Minimal equipment; Low cost; Validated against SOT, good specificity (91%)	Scores can be affected by fatigue and learning effects, poor sensitivity (34–64%)	College athletes; High school athletes; healthy youth; healthy adults
Clinical Test of Sensory Interaction on Balance (CTSIB)	Clinical - Static	6–12 sensory conditions; Firm and foam surfaces; Eyes open, eyes closed, visual conflict dome; Measures time in stance and sway	Easy to administer; Minimal equipment needs; Low cost	Sway measure is often subjective	College and high school athletes (CTSIB); Children and adolescents (P-CTSIB)
Sensory Organization Test (SOT)	Instrumented - Dynamic	Six 20-second balance tests; Firm and moving surface; Eyes open, eyes closed, sway referenced vision; Measures equilibrium score, sensory ratios	Ability to isolate sensory information; Established norms for children; Published literature in concussed athletes	Cost of device, training required, storage and interpretation	College athletes; High school athletes
Tandem Gait	Clinical - Dynamic	Patient performs a heel-to-toe walk for 3 metres, spins 180° and returns to start as fast as they can	Functional activity; Minimal equipment required; Easy instruction to patients; Good intra-rater reliability		Healthy young adults (normative data)
Gait	Instrumented - Dynamic	Normal walking in a laboratory setting; Measured by typical gait parameters	Functional activity; Easy instructions for patients	Require gait analysis instrumentation	Children and adolescents; Mild-to-severe TBI; College athletes

Balance error scoring system

The BESS is a reliable clinical field assessment for postural stability, with scores comparable to the SOT [25, 43]. The BESS consists of six conditions that progressively challenge the sensory systems by altering the stance position (double-leg, single-leg, tandem) and surface (firm, foam) (Figure 1). During the test, patients are asked to stand quietly in the required test position with their hands on their hips. Once the eyes are closed the 20-second trial begins. During each condition, patients are told that, upon losing their balance they should return to the starting position as quickly as possible and continue balancing until asked to stop. The BESS is scored through an error scoring system (Figure 1) where one point is awarded for each compensatory movement (error) made by the patient during each of the six conditions and summed for a total error score where a lower score notes better balance. A standard score of 10 errors is given for each trial if the patient cannot remain in the starting stance for at least 5 seconds of the trial, noting an incomplete attempt. Studies involving the BESS have reported moderate-to-good inter- (0.57–0.96) and intra-rater (0.58–0.98) reliability [44–46] and balance deficits up to 3 days post-concussion [25, 33].

Modifications to the BESS have been studied as a means to improve reliability and make the test more feasible to administer under different conditions (i.e. in hockey skates). Hunt et al. [46] noted better reliability in a modified BESS that included only the single-leg and tandem conditions on the firm and foam surfaces. The Concussion in Sport Group [47, 48] suggested a modification to the BESS that only includes the three conditions on the firm surface to ensure the test could be done under a variety of environmental conditions and in all types of athletes. The BESS is recommended as a clinical balance measure; however, it is important to have properly trained test scorers, test when patients are not fatigued and, when appropriate, administer two baselines to alleviate practice effects.

Gait assessments

Measures of gait can also be used to assess balance following TBI [49–53]. Children with differing severity of TBI were found to be more variable in step time and step length and walk with slower gait speeds compared to healthy controls [49, 54]. Using a more sophisticated motion analysis system, several researchers have found concussed collegiate athletes to demonstrate a more conservative gait strategy [55, 56] that includes decreased gait velocity and increased sway and sway velocity compared to non-concussed peers [55]. A simple measure of gait has been added to the revised Sport Concussion Assessment Tool-3 in the form of a tandem gait task [48]. The tandem gait task requires individuals to walk a distance of 6 metres on a 38-mm piece of tape with an alternating foot heel-to-toe gait. The patient walks 3 metres followed by a 180° turn to return the 3 metres to the starting point. Patients complete four trials with the time of the fastest trial used as the score. Schneiders et al. [53] determined the within-session (ICC = 0.971) and between session (ICC = 0.705) intra-rater reliability of the tandem gait task to be good-to-excellent.

Figure 1. The Balance Error Scoring System conditions and scoring process. Each trial is done for 20 seconds with the score determined by the number of errors during each trial and by summing the six trials to obtain a total score. Errors include lifting the hands off the iliac crest(s), opening the eyes, stepping, stumbling or falling, moving the hip into more than 30° of flexion or abduction, lifting the forefoot or heel or remianing out of the test position for more than 5 seconds.

Self-report outcome instruments

The use of self-report outcome instruments to obtain the patient's perspective following their concussion can be important and relevant, especially with a vestibular component to the injury. Several measures can be used to evaluate dizziness, including the Dizziness Handicap Inventory (DHI), Vertigo Handicap Questionnaire (VHQ) and the Vestibular Disorders Activities of Daily Living Scale (VADL).

Dizziness handicap inventory

The DHI is a 25-item scale consisting of three content domains representing functional (0–48 points), emotional (0–24 points) and physical (0–28 points) aspects of dizziness and unsteadiness [4, 57] and is probably the most used patient-self report scale for vestibular disorders. The DHI scale has both content and criterion validity [57], established test–re-test reliability, requires little time to administer, is easy to score and interpret and may be useful to evaluate the efficacy of treatment [4, 58]. The minimal clinically important difference for the Dizziness Handicap Inventory Scale has been determined to be 11 points [59]. One study of VRT following concussion [60] found a significant and clinically important decrease in DHI score from pre-treatment to post-treatment (49 ± 21 vs. 30 ± 22).

Vertigo handicap questionnaire

This instrument consists of 22-items measured on a 5-point scale that evaluates the effects of vertigo on activities of daily living, social life and leisure activities [61, 62]. This instrument has good internal consistency, test–re-test reliability and discriminant validity. To date the VHQ has not been used with concussed individuals.

Vestibular disorders activities of daily living scale

The VADL consists of 28-items designed to evaluate the patient's self-perception of disablement related to their vestibular disorder [63]. Patients rate their perceived disability on three sub-scales: functional, ambulatory and instrumental tasks. The VADL has good internal consistency, test–re-test reliability, convergent validity with the DHI and discriminant validity [58]. This scale has also not been used with concussed individuals.

Management and treatment of vestibular dysfunction

The vast majority of patients afflicted with vestibular disorders recover spontaneously with only minimal intervention from the medical community [64, 65]. For those that fail to recover or for those who develop more chronic or recurrent conditions, a variety of medical, surgical and therapeutical management options exist. These options include, but are not limited to; counselling, medication, vestibular rehabilitation therapy (VRT), canalith repositioning maneouvres (CRM) for positional vertigo (BPPV) and various home-based exercise programmes. Perhaps the biggest challenge is determining which therapeutic option or which combination thereof to employ, as not all patients respond to each type of treatment equally. Much of the outcome success is dependent upon the onset, aetiology and severity of the vestibular injury as well as

Table V. Vestibular rehabilitation strategies following concussion [76, 77].

Exercise type	Goal	Exercise examples
Habituation	Attempts to minimize the sensitivity to stimuli through repeated exposure to the stimuli	Exercises induce dizziness or vertigo and are done until symptoms resolve
Substitution	Promotes alternative strategies or use of other systems to compensate for the impaired function	Exercises that involve visual or somatosensory cues to force patient to use remaining cues (closed eyes balance, stand on unstable surface)
Adaptation	Assists the CNS to make long-term adaptations to the loss of vestibular input through improved use of functioning aspects of the vestibular system	X1 (moving head) or X2 (moving head and target) exercises that start with a small visual target and move to full field stimulus with distractions

any concomitant conditions which may be contributory to the overall symptom presentation.

For the patient with an acute vestibular injury, the most commonly practiced treatment following diagnosis has been informational counselling and short-term symptom management. This type of plan typically emphasizes the judicious use of medication to control any acute symptoms of dizziness, vertigo, nausea and/or emesis and encouragement to return to normal daily activity as soon as possible to promote normal central compensation processes. Medications typically prescribed under such circumstances include; anti-histamines, anti-cholinergic agents, anti-dopaminergics, benzodiazepines and selective serotonin re-uptake inhibitors (SSRIs) [66, 67]. Generally speaking, these medications have varying inter-subject effects and, while they may be useful in reducing the intensity of symptoms in the short-term, they do little to treat the underlying injury. In fact, because many of these substances have centrally sedating effects, they can paradoxically delay the process of central vestibular compensation and prolong recovery time [68, 69]. Central compensation is the body's unique ability to re-calibrate itself by modulating neural activity following vestibular injury. This is accomplished via a series of adaptive mechanisms triggered by mismatched afferent sensory signals that arise from head and eye movements.

For the patient with a more chronic vestibular injury (i.e. those with symptoms persisting beyond 10–12 weeks), a different therapeutic plan may be employed. In such cases the clinician is left to assume that symptoms persist because proper central compensation has failed to occur or because the initial diagnosis was incorrect and subsequent treatment plan improper. Re-assessment may first be necessary to rule out other aetiologies and to identify any other factors that may be limiting recovery. Assuming accurate diagnosis, however, the treatment plan for the more chronic patient likely will involve a more formalized VRT programme. Vestibular rehabilitation is a broad term used to describe a specialized type of physical therapy that targets the vestibular sensory system. It is concerned with promoting central nervous system compensation following vestibular injury and is common in treating patients with various types of vestibular deficits such as those with central lesions, those with migraine-associated dizziness, those with TBI and those with psychogenic causes that often arise secondarily to a vestibular insult. In general, VRT utilizes symptom-driven activities to de-sensitize the balance system to movements or positions that may provoke symptoms, to eliminate any maladaptive head/body strategies developed as a result of the injury and to promote a more expeditious recovery (Table V). The use of VRT is by far the most common and effective form of treatment for the chronic vestibular patient, with estimated success rates as high as 60–70% [70, 71]. This is particularly true when VRT is customized to the needs of the individual and performed by a properly trained and experienced therapist [72, 73].

While VRT may be new to the sport-concussion literature, its use is widespread in individuals with dizziness [60], vertigo [74] and vestibular injury [75–77]. More recently, attention has focused on the vestibular effects of concussion and the use of vestibular therapy as a rehabilitation intervention following concussion [60]. Alsalaheen et al. [60] retrospectively evaluated the charts of concussed adolescents and adults and reported that a customized VRT programme, that included gaze stabilization, standing balance and walking balance, was successful in reducing dizziness and improving gait and balance in both adolescents and adults. This study shows promise in using VRT following concussion; however, the finding should be interpreted cautiously as the study was a retrospective analysis, used a mixed adult and adolescent population, included non-sport-related concussion and did not use objective measures of vestibulo-ocular function.

Moreover, the timing of when a concussed athlete should begin vestibular therapy is unknown, but deserves discussion. Current recommendations [78, 79] suggest an initial period of rest following concussion until the patient is asymptomatic. Only in cases of prolonged symptoms of dizziness and balance impairment would VRT be implemented. However, there is some evidence to suggest that initiating a VRT programme earlier may be beneficial. In one study, Kammerlind et al. [76] reported that patients had the largest decrease in symptoms and improvements in balance during the first week after initiating a home-based VRT protocol, compared to later follow-up time points. Acute improvements in both eyes-open and eyes-closed balance, tandem walking forward and backwards, visual analogue scale for dizziness and patient-report dizziness scales were found following VRT that included a series of seven exercises targeting quick eye movements, fixating on a target while moving the head, tandem walking, eyes-closed balancing and walking with head movements. These findings may suggest that beginning a vestibular rehabilitation protocol earlier following injury might facilitate greater recovery in the early weeks following injury. Future research should begin to determine the best exercises, timing and patient clinical presentations that may benefit from VRT.

Another type of treatment that may be employed as a result of vestibular dysfunction or included as part of vestibular therapy is canalith repositioning maneuuvres (CRM). Canalith repositioning is a broad term used to describe a series of physical manipulations used to treat benign paroxysmal positional vertigo (BPPV) of the inner ear. BPPV is a specific vestibular condition that arises when calcium carbonate particles from the otolithic organs (utricles) become displaced into the semicircular canals of the peripheral vestibular organ. BPPV causes abrupt paroxysmal vertigo, nausea and in some cases emesis when the individual orients their head in such a manner that causes the displaced otoconia to move within the semicircular canal. BPPV typically occurs as a result of trauma, infection, ageing or in many cases idiopathically. The goal of the canalith repositioning treatment is to mechanically move the displaced otoconia out of the semicircular canals and back into the utricle via a series of head position changes with respect to gravity. Once in the utricle, the otoconia can re-adhere, dissolve or be re-absorbed by the body so they cannot cause further symptoms. Canalith repositioning can be performed in the clinic or at home (as directed by the clinician) and has been shown to be highly successful in the treatment of BPPV with various studies reporting success rates as high as 96% for symptom resolution [80]. Additionally, for those that undergo in-office treatment, greater than 90% of afflicted individuals report complete resolution after only 1–2 sessions [81, 82].

Current recommendations

The potential for concussion to affect vestibular function is significant. Recommendations for an evaluation of balance and vestibular function have been made in several positions or consensus statements [14, 79, 83, 84]. The most recent guidelines from the Concussion in Sport Group [83] suggest that gait and balance should be included as part of the concussion assessment, especially in the first 72 hours post-concussion and when the symptom presentation includes a balance component or dizziness. The American Medical Society for Sports Medicine's [79] statement describes balance testing as specific, but not sensitive for detecting concussion-related impairments. Furthermore, it cautions the interpretation of some balance assessments that can be influenced by other factors during the sideline evaluation, such as lower extremity musculoskeletal injuries, tape or braces, type of footwear and fatigue. Regardless, clinicians should be aware of the potential vestibular consequences following concussion and assess using tests of oculomotor function and balance. Any deficits should resolve prior to allowing an athlete to engage in a return-to-play progression.

Conclusion

Concussion can result in vestibular and balance dysfunction and there is a need for clinicians to assess for and treat any dysfunction during the patient's recovery. There is consensus that vestibular and balance assessments be included in the concussion assessment battery and when available objective measures be used. Preliminary evidence suggests that VRT may be useful in vestibular symptoms and improving patient outcomes; however, more controlled prospective trials are needed to determine the best rehabilitation regiment. Future studies should continue to explore vestibular deficits, the sensitivity of vestibular and balance assessments for assessing concussion and the use of VRT to facilitate recovery.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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