Sport-related Concussions and Subsequent Balance and Vestibular Deficits

The Centers for Disease Control estimates that 1.6 to 3.8 million concussions occur in organized and recreational sports each year, and this figure is largely under powered secondary to many individuals not seeking medical attention for such injuries1. This shocking statistic demonstrates the need for improved identification and management of sport-related concussions. Additionally, there has been an increase in the prevalence of sport-related concussions, as a study by Schallmo et al. found that there was a significant increase in the overall number of concussions for all sports, the overall concussion rate, and the overall proportion of concussions from the years 2005 to 20142.

The definition of sport-related concussion has been an area of continuing work, but the most recent definition per the 2016 meeting of the Concussion in Sport Group is, “a traumatic brain injury induced by biomechanical forces”3. The definition is further detailed by common features, which can include: “caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head”, “results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously”, “may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies”, and “results in a range of clinical signs and symptoms that may or may not involve loss of consciousness… in some cases symptoms may be prolonged”3.

In exploring common mechanisms of injury (MOI) for sport-related concussions, it is clear that they are variable based on sport and gender. In general, it has been hypothesized that concussion is the results of linear and rotational head accelerations4. A study by Delaney et al. investigated mechanisms of injury for athletes playing collegiate football, ice hockey, and soccer5. A strike to the temporal area of the head or helmet was the most common MOI and occurred in all three sports5. In football and soccer, contact from another player’s head or helmet was the most likely mechanism, and in hockey, concussions were more likely to occur with contact with another body part besides the head5. In all sports, however, the overall rate of concussion has been found to be higher in females, and this could be due to biomechanical differences like body bass and neck strength4. Understanding the concussive mechanism of injury is important in physical therapy evaluation, and can help to explain impairments and concomitant symptoms.

Symptoms seen with concussion are also variable, but can be divided into four general categories: physical, cognitive, emotional, and sleep-related4. These symptoms can appear immediately or can develop over the course of days to months4. Physical symptoms can include headache, dizziness, reduction in oculomotor control, nausea, vomiting, gait unsteadiness, balance problems, and fatigue4. Cognitive symptoms can include post-traumatic amnesia, difficulty concentrating, and memory problems4. Common emotional symptoms are irritability, emotional lability, and depressed affect4. Lastly, sleep symptoms can include difficulty falling asleep, drowsiness, and changes in sleeping patterns4.

The recognition of the role of vestibular and oculomotor dysfunction in concussion management is a relatively new concept in this field, but the consensus by the Concussion in Sport Group is that all athletes should have a clinical neurological assessment that includes evaluation of cognition, oculomotor function, sensorimotor function, gait, coordination, vestibular function, and balance3. Vestibular and oculomotor dysfunction is also important to address because it is directly associated with prognosis6. It has been reported that 67-77% of athletes’ report dizziness after concussion, and an initial presentation of dizziness is a negative prognostic indicator and a predictor of a lengthened recovery for sport-related concussions6. An interesting finding is that abnormalities on vestibular-ocular reflex (VOR) testing or tandem-gait performance led to a 53-day increase in recovery time as compared to controls without vestibular involvement7. Additionally, there is a high correlation between reports of dizziness and balance impairments and increased postural instability in athletes post-concussion6. Lastly, oculomotor involvement has also been correlated with increased cognitive impairment and prolonged recovery7.

The vestibular system consists of the three semicircular canals that detect rotations acceleration and two otolith organs that detect linear acceleration6. These structures gather information about the movement of the body and transmit it to the brainstem, which then leads to a motor response6. There are also two distinct reflexes that are integrated with the vestibular system to produce motor responses, the vestibulospinal that controls postural stability and the vestibulo-ocular that integrates movement of the head and vision7. There are specific brain areas responsible for these functions, including the cerebellum, cerebral cortex, thalamus, reticular formation, and brainstem7. Therefore, a concussion that causes disruptions of the inner ear structures or of any of the brain areas disrupts the vestibular system and leads to the presentation of symptoms7. Vestibular symptoms commonly seen post-concussion include dizziness, nausea, vertigo, blurry vision, unstable vision, and discomfort in busy environments7.

Oculomotor control is the result of versional eye movements, such as pursuits and saccades, and vergence eye movements such as convergence and divergence7. These eye movements, combined, change the angle of gaze to hold images steady7. Additionally, there is an interplay of these movements with the vestibular system7. Brain areas that are responsible for these functions include the midbrain, cerebellum, pons, and the cerebral cortex7. Concussions result in the disrupted function of these brain areas, and thus issues with eye movement control7. Common oculomotor symptoms include blurred vision, impaired convergence, difficulty reading, diplopia, headaches, difficulty in tracking moving targets, eye strain, dizziness, and deficits in scanning for visual information7.

Post-concussion syndrome (PCS) is the persistence of concussion past the typical time for recovery8. It has been found that about 10% of athletes will have these persistent symptoms greater than 2-weeks post injury8. The most sensitive criteria to define PCS is the presence of three or more of the following symptoms, including: headache, dizziness, fatigue, irritability, insomnia, concentration difficulty, or memory difficulty8. The difficult task with identifying PCS is teasing out the presence of other secondary conditions like depression, chronic pain, cervical injury, vestibular dysfunction, or visual dysfunction8. Additionally, there is much debate that PCS has a psychogenic origin, thus making diagnosis and management more challenging8. One method that has been described in the literature to differentiate between PCS and psychological symptoms is to see whether symptoms are exacerbated with exertion and improved with rest8. The literature supports the use of a standardized treadmill testing using the Balke protocol, and it will be noted that the symptoms are exacerbated throughout the test and improved with rest8. If the symptoms are not exacerbated by this test, then it is likely that a secondary condition is causing the symptoms8. Furthermore, if the symptoms are exacerbated with minimal activity and not responsive to rest, it is likely psychological stresses at play8. Factors that increase the risk of PCS are history of prior concussions, being female, younger age, having a history of cognitive impairment, and having a history of psychological disorders8.

The remainder of this review of literature will be focused on a patient with post-concussive syndromes that is experiencing balance problems and vestibular complaints. Specific outcome measures for vestibular complaints are important for diagnosing true vestibular involvement and for tracking progress with therapy. The Vestibular/Ocular-Motor Screening (VOMS) tool was developed to be a brief screening tool that can be used in conjunction with the comprehensive examination and interview. The VOMS looks at symptom provocation with 5 domains: smooth pursuit, horizontal and vertical saccades, convergence, horizontal and vertical VOR, and visual motion sensitivity. The patient rates their symptoms (headache, dizziness, nausea, fogginess) before and after assessment of each of the 5 domains on a scale of 0 to 10 with 0 being no symptoms present. The VOMS has been shown to have strong internal consistency and significant correlation with the Post-Concussion Symptom Scale (PCSS), which is another option for use in a patient population like the one described above. The PCSS is a 21-item self-report measure that looks at symptom severity on a 7-point Likert scale. This scale has been found to have moderate test-retest reliability, is sensitive enough to detect reliable change, and has convergent validity with neurocognitive measures.

Another outcome measure that would be helpful in determining the origin of patient-reported dizziness is the Dizziness Handicap Inventory. This is a self-reported measure of 25 items that assessed the functional, physical, and emotional effects of dizziness over the course of a month. It is able to provide information about the cause of dizziness, as it asks questions about when and where dizziness occurs. Lastly, it has been shown to improve significantly following vestibular rehabilitation, therefore justifying its use in a patient being seen in physical therapy for vestibular complaints. A final outcome measure that can be used is the King-Devick test, which looks at saccadic eye movements. This assessment consists of a series of 4 cards, each with 8 rows of 5 numbers. The patient must read the numbers out loud as quickly and accurately as possible, and the time and number of errors are recorded. This test has been validated in the sport-concussion population, and has been correlated with scores on the Post-Concussion Symptom Scale and on other cognitive assessment tools. It is important to note, however, that the King-Devick test does not fully measure oculomotor function, as it does not measure smooth pursuits, convergence, or accommodation, and it does not assess any vestibular components.

Though there are a lot of balance outcome measures at our disposal, those that have been validated in the concussion population would best serve a patient who is experiencing balance difficulties post-concussion. The Balance Error Scoring System (BESS) is an easily administered balance assessment that has been shown to be comparable to the Sensory Organization Test, which requires special technology to administer6. It consists of six conditions that progressively challenge the sensory system to a greater degree, either by changing stance (double-leg, single-leg, tandem) and/or changing the surface (firm and foam)6. The participant is asked to stand in the position for 20 seconds with hands on hips and eyes closed, and the total number of errors are counted until the time has expired6. The BESS has been found to have high content validity in identifying balance deficits in the concussion population, and has been found to have moderate to good reliability10. Additionally, a study by Murray et al. that compared the validity of various balance measures in athletes with concussion found that the BESS demonstrated moderate to high reliability and low to moderate validity, thus supporting its utilization11. On the other hand, the data did not support the use of the Romberg test, the Sensory Organization Test, the Wii Fit, and the Clinical Test of Sensory Organization and Balance11.

Another balance outcome measure that could be used in a patient describing balance difficulties post-concussion is the high-level mobility assessment tool (HiMAT)12. This tool was developed for the TBI population to quantify both high-level mobility and balance12. The HiMAT consistes of 13 walking, running, skipping, hopping, and stair tasks that are measures based on performance, with zero being inability to perform the item and 4/5 being the highest scores possible12. It has been demonstrated to have high inter-rater reliability, test-retest reliability, and internal consistency in patients with moderate and severe TBI12. Additionally, a study by Kleffelgaard et al. analyzed its appropriateness in the mTBI population12. It was found that the inter-rater and intra-rater reliability of the summed score was high, there was good responsiveness, and the HiMAT did a good job discriminating between patients that perceived improved balance versus no improvement12. Furthermore, the ceiling effect was 22.8%, which is a good assessment to use in the majority of people12. This test is particularly applicable in the athletic population, as it is higher level than a test like the BESS and it tests functions that athletes need to be able to perform well in order to return to play12.

Lastly, a combined gait and balance measure would be appropriate to assess dynamic balance in patients who have had sustained a concussion6. Studies have found that concussed athletes demonstrate more conservative gait that is manifested in decreased gait velocity, increased sway, and increased sway velocity6. The Functional Gait Assessment (FGA) is a 10-item test that is based on the Dynamic Gait Index, and is commonly used in studies researching concussion outcomes14. The items include: “gait level surface, change in gait speed, gait with horizontal head turns, gait with vertical head turns, gait and pivot turn, step over obstacle, gait with narrow base of support, gait with eyes closed, ambulating backwards, and steps”14. The FGA was developed to assess balance in individuals with vestibular dysfunction, and thus would be particularly appropriate in patient cases where both symptoms are present14. The FGA has been found to have high inter-rater (ICC=0.84) and intra-rater (ICC=0.83) reliability for total scores, and good internal consistency14. Furthermore, the FGA has been found to be responsive to change in people with balance and vestibular disorders14. Much like the HiMAT, this measure is good for use in the athletic population, as it assesses higher level mobility skills and is also very functional when thinking about return to play.

In describing treatments and interventions for an individual with vestibular complaints and balance difficulties, it is important to note that many rehabilitation programs employ combined treatments secondary to the interconnectedness of the vestibular system and balance. One of the most frequently cited, and most effective, interventions for individuals with vestibular complaints following a sport-related concussion is vestibular rehabilitation therapy6. The challenging aspect to vestibular rehabilitation therapy, however, is in deciding which treatment to employ based on the patient’s chief complaints, evaluation findings, and symptom severity, as individualized strategies have been found to be the most effective6. A study by Alsalaheen et al. found that patients who attended at least 1 session of vestibular rehabilitation had improvements in gait, balance, and perceived dizziness and balance confidence7. Additionally, a randomized controlled trial by Schneider et al. found that cervicovestibular rehabilitation was effective in reducing the time needed to be cleared medically post-concussion7. In this study, there was a control group who underwent weekly sessions that focused on postural education, range of motion exercises, cognitive and physical rest, and a graded exercise program, and an intervention group who completed the same sessions with the addition of individualized cervical spine and vestibular rehabilitation7. The intervention group had 73% cleared at 8-weeks, whereas the control group had 7% cleared7. With these studies in mind, it is evident that a personally tailored, comprehensive vestibular rehabilitation protocol is effective in both return to activity and in improving symptoms, gait, and balance.

The general theory with vestibular rehabilitation therapy is that is uses activities that exacerbate the symptoms to desensitize the system in a controlled way6. A study by Valovich et al. describes three general strategies for vestibular rehabilitation that all exercises fall underneath6. Habituation exercises attempt to minimize sensitivity to certain stimuli by repeatedly exposing the patient in a controlled fashion6. The second strategy is substitution exercises in while the goal is to promote the use of other sensory systems to compensate for the affected one6. Lastly, adaptation exercises promote central nervous system long-term adaptations to the loss of vestibular input by using the other parts of the vestibular system that are still functioning6.

Another study by the previously mentioned Alsalaheen et al. explored the pattern of vestibular rehabilitation exercise prescriptions given to patients post-concussion15. This study was a retrospective study in which the researchers reviewed the charts of 114 patients referred to a vestibular rehabilitation clinic15. This study is particularly helpful because it provides an overview of the most commonly used exercises for patients with vestibular complaints15. The exercises prescribed were divided into 5 categories15. Eye-head coordination exercises were focused on vestibulo-ocular reflex gain adaptation, symptom habituation, and oculomotor re-education15. The commonly utilized exercises within this category were VORx1, VORx2, VOR cancellation, convergence, smooth pursuits, anticipatory gaze shifts, imagined target, and saccades15. The next category of exercises was sitting balance exercises, that focused on maintaining balance with upright sitting, with weight shifts, and with bouncing15. The third category of exercises were standing static balance exercises, that included maintaining static stance in various conditions such as on one leg, on a rocker board, and with one foot on a step15. The fourth category of exercises are those for dynamic standing balance, and they included reaching outside of base of support, marching in place, stepping forward and backward, side stepping, stepping up or down, and turns15. Lastly, there was the category of ambulation exercises, that included forward walking, backward walking, stairs, walking with turns, grapevine walking, skipping, jogging, and running15. This study found that 95% of the participants received eye-head coordination exercises, and that the VORx1(3 times/day, 60 seconds each), VORX2 (1 time/day, 30 seconds), VOR cancellation (2 sets of 10 repetitions), and convergence (2 sets of 10 repetitions) were the most common of that category15. The values in parentheses represent the most common frequency and duration specified by the physical therapists. Static standing balance was the next most prescribed category at 88%, and the most frequently prescribed exercises were standing on level and foam surfaces (2 times/day, 30 seconds each), single leg stance (4 times/day, 30 seconds each), weight shifting in all directions (1 set, 10 repetitions), and sit to stand exercises (1 set, 10 repetitions)15. The ambulation category was the third most prescribed category at 76%, and the most commonly utilized activities were forward walking, backward walking, walking with turns (1 set, 20 head turns), and tandem walking with head still (1 time, 20-foot distance)15. Lastly, this study delved into common progression patterns. Common progressions for the eye-head coordination exercises were sitting, to standing feet together, to standing feet apart, to walking, to standing on a foam surface15. Common progressions for the static standing balance exercises were change in surface, base of support (feet together, semi-tandem, tandem, single-leg stance), visual input (eyes opened vs eyes closed), and the addition of head movement with the exercises15.

As seen and mentioned above, many of the interventions utilized in vestibular rehabilitation also address improving static and dynamic balance. Another intervention that is important in addressing balance difficulties in patients post-concussion is dual-task activities16. Though there have been no direct studies that have looked at the effectiveness of dual-task interventions in improving balance post-concussion, there is a plethora of data on the deficits that people with concussion present with under dual-task conditions16. A systematic review by Mihalik et al. looked at the usefulness of divided attention tasks that included both cognitive and motor components in concussion management16. The major takeaways from this study were that, following, concussion, many individuals have greater response times, less efficient gait strategies (more postural sway), decreased gait velocity, and decreased postural control16. These findings justify the need to incorporate dual-task practice and dynamic balance activities in therapy. The methods and measures used to assess dual-task performance can also be used as interventions in individuals who demonstrate balance difficulties under said conditions. The most commonly reported methods, that can be extrapolated to interventions, included gait and walking tasks with a cognitive challenge and/or obstacles to avoid16. Cognitive challenges can include memory and recall challenges, question and answer tasks, arithmetic tasks, counting tasks (forward or backward), visual scanning tasks, and auditory response tasks such as changing gait direction when an auditory cue is given16. Participating in sports frequently requires divided attention and ability to rapidly process cognitive and motor information, so dual-task interventions such as those suggested are critical in assessing readiness to return to play.

The challenge in concussion management and rehabilitation is the wide variability in symptoms and presentation, thus justifying the need for a comprehensive, detailed evaluation and personally tailored plan of care. Vestibular, vestibulo-ocular, and balance dysfunctions after concussion are very common, yet are often underemphasized in rehabilitation. Understanding the common deficits noted in this review, as well as commonly used, evidence-based interventions can help therapists in being better equipped to address sport-related concussions from the perspective of the many systems involved. This knowledge also assists in the assessment of readiness to return to sport in athletes, as much of these higher level impairments can be missed if not assessed and treated appropriately.

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