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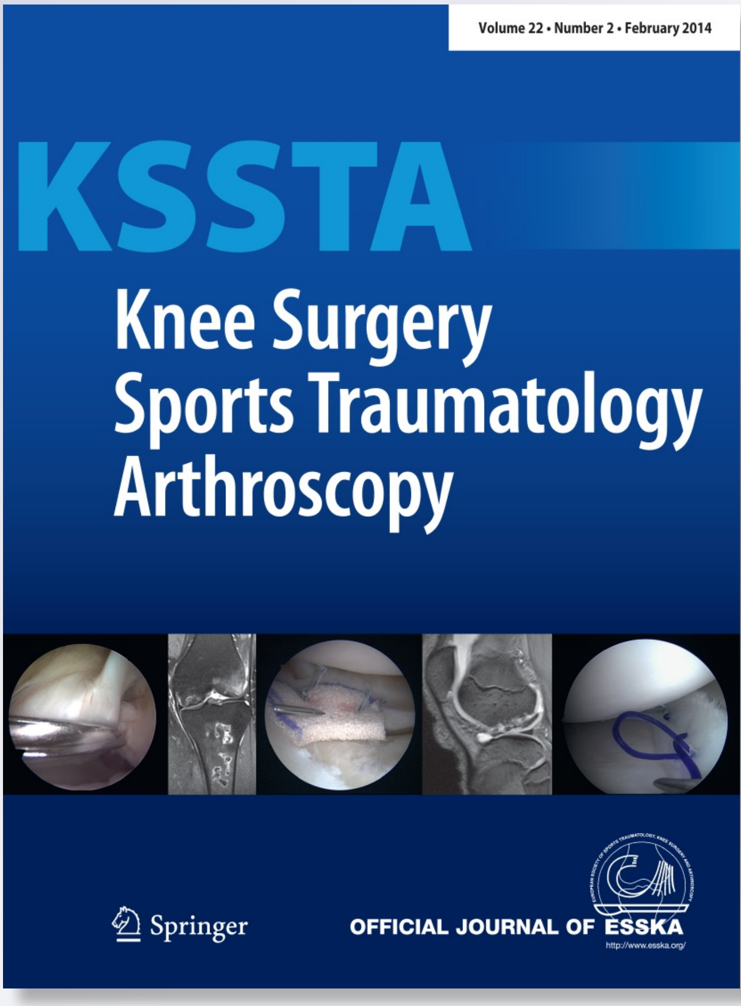
Knee Surgery, Sports Traumatology, Arthroscopy

ISSN 0942-2056
Volume 22
Number 2

Knee Surg Sports Traumatol Arthrosc
(2014) 22:235-246
DOI 10.1007/s00167-013-2791-6



Springer

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SPORTS MEDICINE

A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion

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Received: 4 November 2013 / Accepted: 20 November 2013 / Published online: 12 December 2013

Abstract

Purpose The purpose of this paper is to discuss risk and prognostic factors for concussion outcomes, review comprehensive approaches to assessment, and describe a new method for conceptualizing treatment for sport-related concussion using clinical experience.

Methods Based on the current literature of sport-related concussion and clinical experience, an approach for conceptualizing concussion care using clinical trajectories and targeted treatments was developed.

Results A comprehensive approach to assessment and targeted treatments for sport-related concussion was developed using specific clinical trajectories.

Conclusion Sport-related concussions are heterogeneous and require an individualized clinical approach. The use of a comprehensive approach for assessing specific clinical trajectories following a sport-related concussion will help clinicians better conceptualize this injury. Clinicians can then match targeted treatment pathways to specific clinical trajectories to accelerate safe return to play for athletes following a sport-related concussion.

Level of evidence V.

Keywords Concussion · Mild-traumatic brain injury · Neurocognitive testing · Return to play

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Introduction

Each year, there are between 1.6 and 3.8 million sport-related concussions in the United States alone [38]. A concussion is caused by direct or indirect biomechanical forces, including linear acceleration–deceleration and rotational forces acting on the brain. These forces result in a neurometabolic energy crisis in the brain, wherein levels of extracellular potassium and intracellular sodium and calcium are increased [13]. Following a concussion, athletes may experience any or all of approximately 21 disparate symptoms, including headache, dizziness, confusion, and difficulty concentrating (Table 1); as well as cognitive, vestibular, and ocular motor impairments. Traditionally, and in spite of the myriad symptoms and impairments following concussion, this injury has been conceptualized and assessed from a homogeneous perspective. This "one size fits all" approach to concussion care does not address the highly individualized nature of this injury and can result in ineffective management strategies. A new conceptual approach to sport-related concussion that emphasizes the heterogeneity of sport-related concussion is warranted. Such an approach will help to inform the clinical care of concussed athletes, as well as establish guidelines for assessment and management of this injury moving forward.

The purpose of the current paper is to present a new conceptual approach to sport-related concussion based on current empirical evidence and clinical experience. This approach involves: (1) understanding the role of risk factors associated with each athlete and the prognostic factors associated with each injury, and how they can influence clinical outcomes; (2) a comprehensive assessment, including clinical interview, vestibular, and ocular motor screening, computerized neurocognitive testing, and, in some cases, neuroimaging; and (3) identification of concussion

Table 1 Common concussion symptoms

1. Headache
2. Nausea
3. Vomiting
4. Balance problems
5. Dizziness
6. Fatigue
7. Trouble falling asleep
8. Sleeping more than usual
9. Sleeping less than usual
10. Drowsiness
11. Sensitivity to light
12. Sensitivity to noise
13. Irritability
14. Sadness
15. Feeling more emotional
16. Numbness or tingling
17. Feeling slowed down
18. Feeling mentally "foggy"
19. Difficulty concentrating
20. Difficulty remembering
21. Visual problems

clinical trajectories and targeted treatment pathways. A summary of this new conceptual model for the clinical care of sport-related concussion is provided in Fig. 1.

Empirically based risk and prognostic factors for concussion

Sport-related concussion is a heterogeneous injury that is characterized by a myriad of symptoms, variable clinical presentations, and recovery trajectories. Although approximately 80 % of patients recover within 3 weeks, 20 % of athletes take over 3 weeks to recover following sport-related concussion [18]. This variability in recovery and other outcomes may be attributed, in part, to risk factors associated with concussion (Fig. 1). Risk factors can be categorized as primary, existing prior to the injury (i.e. premorbid), and secondary, occurring post-injury (i.e. prognostic).

Risk factors for concussion outcomes

Pre-morbid risk factors are associated with increased deficits and protracted recovery following sport-related

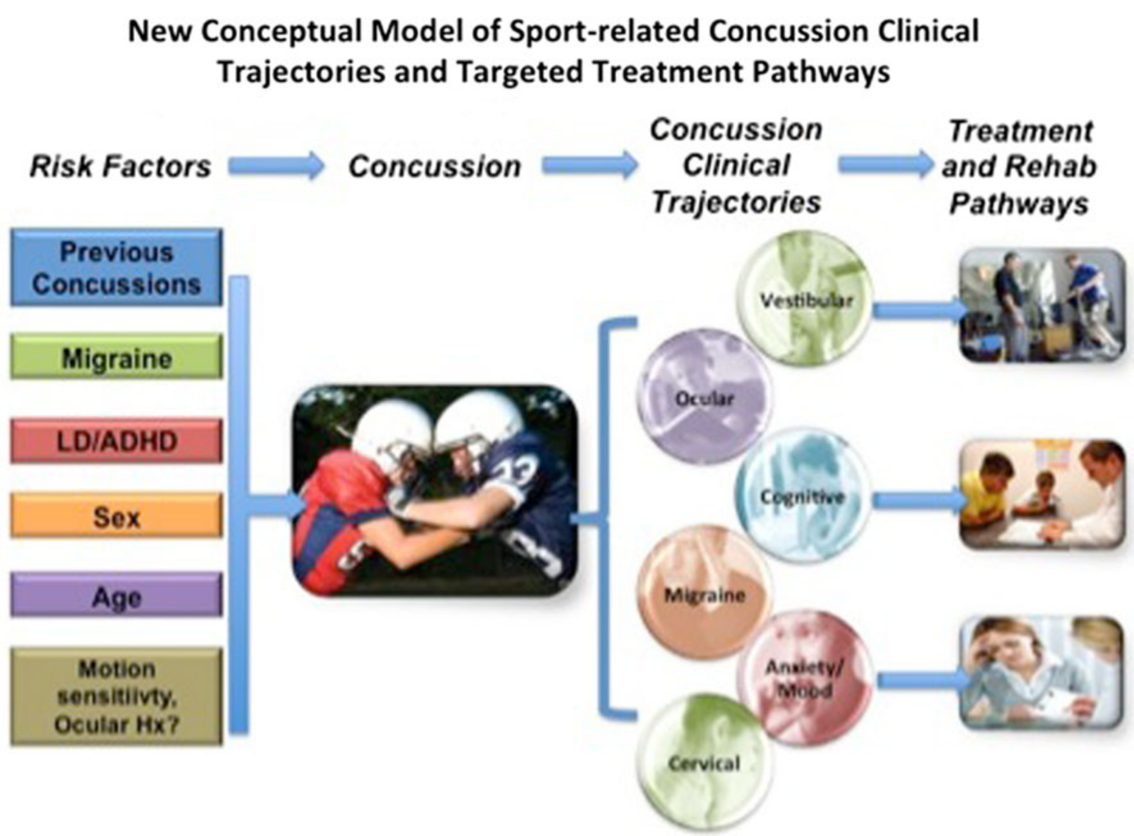

Fig. 1 New comprehensive conceptual model for clinical care of sport-related concussion

concussion. Risk factors include a history of concussion [40], history of migraine [19], diagnoses of learning disability or attention-deficit hyperactivity disorder (ADHD) [6, 9] sex (i.e. females) [7, 8] and age (i.e. younger) [10, 36]. It is thought that migraine history may, in part, explain sex difference in concussion outcomes as females have a higher likelihood of having migraine. Patients with these risk factors may need to be identified for early concussion assessment following suspected acceleration/deceleration or rotational forces to the head and provided with more conservative care and frequent follow-ups after their injury.

Prognostic indicators for protracted recovery and poor outcomes

Researchers have identified several post-injury factors that may negatively affect a patient's recovery. The occurrence of post-traumatic migraine symptoms following concussion (headache with nausea and photo and/or phonosensitivity) (PTM) [24], immediate dizziness [23], and sub-acute (within 3–7 days) fogginess, difficulty concentrating, vomiting, dizziness, nausea, headache, slowness, imbalance, photo/phonosensitivity, and numbness predict longer than normal (i.e. 14–21+ days) recovery times [23]. In patients that complete post-injury computerized neurocognitive testing, a score that deviates three or more Reliable Change Indices (RCI) relative to baseline suggests a 94 % chance of recovery lasting more than 10 days [17]. Specific cut-off scores for each clinical composite with computerized neurocognitive testing are also available to predict recovery times of greater than 1 month with up to 85 % sensitivity [22]. Although there are not yet supporting data, clinical experience suggests that earlier treatment of secondary risk factors may lead to a more rapid recovery.

Emerging predictors

It has been speculated that a pre-existing history of vestibular dysfunction (e.g. motion sickness) and ocular motor dysfunction (e.g. nystagmus, strabismus) may also be risk factors for poor outcomes following sport-related concussion. Although these risk factors have not yet been established empirically, sports medicine professionals should be aware of the history of these emerging risk factors, particularly in patients with vestibular and ocular motor clinical trajectories, as discussed later in this paper.

Comprehensive approach to assessment

A comprehensive approach to the assessment of athletes with sport-related concussion should combine the depth of information from clinical interviews with the breadth of information provided by implementing assessment tools representing multiple domains including symptoms, neurocognitive functioning, vestibular, and ocular motor. In so doing, clinicians will be able to better identify and conceptualize specific clinical trajectories following concussion and develop more targeted rehabilitation strategies for each athlete. Depending on the case and history of each athlete, additional in depth assessments via psychological, vestibular, and vision referrals may be warranted. A comprehensive assessment following concussion begins with the clinical interview.

Clinical interview

The clinical interview is the first line of communication between a clinician and a patient. The interview serves to gather information and build a relationship. It is through this process that the clinician may develop a better understanding of both the athlete and the injury itself. The goals of the clinical interview should be as follows: (1) establish a therapeutic alliance, (2) determine and describe the mechanism of injury, as well as acute and chronic symptom presentation, and (3) obtain a detailed history including personal and family medical history, as well as a comprehensive biopsychosocial history. It is important for the clinician to gather injury information in partnership with on-field medical providers (e.g. physiotherapist, team physician). Relevant on-field injury information includes initial signs [e.g. loss of consciousness (LOC), post-traumatic amnesia (PTA)] and symptoms (e.g. dizziness, headache), as well as details about the mechanism and location of injury. The clinician may also incorporate information from sideline assessment tools, such as the Sport Concussion Assessment Tool-3 (SCAT-3), which includes brief assessments of signs and symptoms, balance, and memory. However, although tools such as the SCAT-3 are useful in the initial assessment of the injured athlete, they should be augmented by the clinical interview and additional, more validated clinic-based assessments. In particular, the SCAT-3 does not adequately assess neurocognitive function (e.g. reaction time, processing speed, design memory) and does not include any vestibular or ocular motor assessments. Once the injury information is gathered, the clinician can begin to conceptualize the patient's risk factors, clinical trajectories, and targeted rehabilitation pathways. The clinical interview is a complex and evolving process that requires the combination of a systematic organizational approach together with clinical acumen based on cumulative clinical experience working with concussed athletes. One of the key focus areas of the clinical interview is the symptom(s) of the athlete.

Symptoms

Symptoms are typically assessed using a combination of self-report questionnaires and clinical interview questions. It is important to assess which symptoms athletes report, when they occur, and if they become worse with activity. Moreover, the severity of symptoms needs to be considered, in addition to the total number of symptoms endorsed on reports or during the clinical interview. The most common symptom in the first week following sport-related concussion is headache, with about 75 % of patients reporting this symptom [30]. As mentioned earlier, dizziness at the time of injury and migraine symptoms in the first week following injury should be given special attention, as they indicate poor outcome and longer recovery time. Concussion symptoms vary based on time. Researchers have reported that within the first week of injury, a global cognitive-fatigue-migraine symptom predominates [20]. The existence of such a global symptom factor reinforces the notion of rest (to varying degrees) in the first week post-injury for most, though not all (e.g. predominately ocular motor) athletes. Other researchers [35], and prevailing practice, support four distinct symptom factors—cognitive, migraine, emotional, and sleep-related—at 1+ weeks post-injury. Although further research is warranted to determine which symptom factors occur after 1 week post-injury, symptoms delineate into the clinical trajectories including cognitive/fatigue, vestibular, ocular motor, anxiety, migraine, and cervical symptoms presented later in this paper.

Vestibular and ocular motor screening

Vestibular and ocular motor findings can provide valuable clinical data for patients following concussion. Recently, researchers have reported that vestibular impairment is common following concussion [16, 33]. Approximately 50 % of athletes report dizziness as a symptom in the first few days following concussion [25]. Symptoms of vestibular impairment may include unstable vision, difficulty focusing, motion discomfort, difficulty in busy visual environments, and imbalance—particularly in the absence of visual input—and dizziness. Dizziness at the time of injury has been shown to play an important role in predicting protracted recovery [23]. In fact, dizziness at the time of injury was associated with a nearly sevenfold increase in risk for a protracted recovery (i.e. 21+ days) [23]. However, dizziness can have multiple aetiologies. Consequently, it is important to determine whether the cause of dizziness following concussion is from migraine, cervicogenic, psychiatric, or central or peripheral vestibular dysfunction. Dizziness following concussion may also involve impairment in vestibular and ocular motor function and integration.

Ocular motor problems are experienced by approximately 1/3 of athletes in the first week following a concussion [20]. Ocular motor dysfunction is present up to 65 % of patients following concussion [4]. Ocular motor dysfunction may result from problems associated with vergence, accommodation, version, and alignment [5]. As a result, athletes may experience blurred vision, diplopia, difficulty reading, eyestrain, headache, loss of place when reading, and difficulty with visual scanning. These issues may in turn manifest as poor academic or work performance, motion sensitivity, and discomfort in moving vehicles—all of which can impair the recovery process. Ocular motor dysfunction has received little attention from researchers and clinicians, resulting in few practical methods of assessment. Recently, researchers have focused on saccadic eye movements using the King–Devick test. Although these tests provide additional data on ocular motor dysfunction, they do not assess other areas of ocular motor function such as pursuits, vergence, and accommodation, which, based on clinical experience and empirical data, are often affected following concussion.

The measurement of imbalance has traditionally served as a proxy for vestibular impairment following concussion. Balance impairments have been reported subjectively by nearly 40 % of athletes in the first few days following concussion [20], and researchers have reported objective balance impairments out to 30 days [2, 12, 28]. Balance impairment following concussion is most commonly assessed via clinical assessments such as the balance error scoring system (BESS) [11, 37] and laboratory assessments such as the sensory organization test [34]. However, these are static tests of only the vestibulo-spinal aspect of the vestibular system and do not address the dynamic aspects of the vestibular system, including vestibulo-ocular control. Impairment resulting from the involvement of vestibulo-ocular function may be overlooked when using static vestibulo-spinal measures alone. A more comprehensive, but brief, measure that combines vestibular and ocular motor assessment is warranted.

Recently, researchers and clinicians from the University of Pittsburgh Medical Center's (UPMC) Sports Medicine Concussion Program have developed and tested a new, brief assessment of vestibular/ocular motor dysfunction for use with athletes following sport-related concussion. The UPMC vestibular/ocular motor screen (VOMS) was developed to assess vestibular and ocular motor impairment via patient-reported symptom provocation following each assessment. The VOMS consists of brief assessments of the following five domains: (1) smooth pursuits, (2) horizontal and vertical saccades, (3) convergence, (4) horizontal and vertical vestibular ocular reflex (VOR), and (5) visual motion sensitivity. Patients verbally rate changes in headache, dizziness, nausea, and fogginess symptoms compared to their pre-assessment state on a scale of 0 (none) to 10 (severe) following each VOMS assessment to determine whether each assessment provokes symptoms. Convergence is assessed by both symptom report and measurement of the near point of convergence (NPC). NPC values were averaged across 3 trials. According to the literature, NPC values up to 5 cm are considered normal [42]. The VOMS takes approximately 5 min to administer to each patient. Preliminary data indicate that the VOMS is a distinct construct from imbalance and predicts neurocognitive impairment and symptoms following sport-related concussion. Use of tools such as the VOMS will allow clinicians to identify athletes who require additional specialized vestibular and ocular motor testing and referral. These tools will also allow clinicians to identify athletes who may require specialized vestibular and vision therapy early in the recovery process, which in turn may expedite their recovery.

Neurocognitive testing

Computerized neurocognitive testing (NCT) provides an essential tool in a comprehensive approach to assessing sports-related concussion. Current computerized NCTs include the automated neuropsychological assessment metrics (ANAM), AXON/CogSport, CNS Vital Signs, Headminders, and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT). These tests typically take 20–30 min to complete and assess patient demographics—including age, sex, concussion history, and injury information; concussion symptoms—including headache, nausea, dizziness, and memory problems; and cognitive tests—including attention, memory, processing speed, and reaction time. Computerized NCTs provide advantages over traditional paper and pencil testing including taking less time to administer, the ability to present randomized stimuli and avoid practice effects of testing, being less expensive, and providing instant data without the need for long scoring and interpretation lag time.

Among computerized NCTs, ImPACT is the most widely utilized tool and has extensive published psychometric data to support its use. The test includes the Post-Concussive Symptom Scale (PCSS), as well as six cognitive modules that comprise four clinical composite scores covering visual and verbal memory, processing speed, and reaction time. The test also includes built-in validity measures to detect individuals who are not completing the test with full effort. The ImPACT test produces a clinical report that includes demographics, symptoms, and cognitive performance data. This report provides an intuitive and easy to understand representation of both the cognitive effects and recovery from concussion. Ideally, baseline neurocognitive testing is recommended for athletes to allow for an intraindividual comparison of pre- to post-injury performance. However, age and sex-specific normative data are available for patients aged 11–60 years and may be used to interpret post-injury data when a baseline is unavailable.

The ImPACT cognitive assessment tool is supported by extensive data with respect to prognostic ability, reliability and validity. Researchers have reported 94.6 % sensitivity and 97.3 % specificity for ImPACT in detecting neurocognitive deficits in a population that was otherwise asymptomatic [41]. Further, in a study of healthy collegiate American football players participating in contact sports, researchers reported no statistically significant changes in composite ImPACT scores when the test was administered during the pre-, mid-, and post-seasons [32]. This stability in text performance across a season suggests that any changes that might be evidenced on computerized neurocognitive testing would be related to the effects of concussion. In addition, as these neurocognitive deficits are typically present for a period of time beyond symptom resolution [31], this finding underscores the need to utilize neurocognitive testing as part of the clinical decision-making process for safe return to play. In this regard, a study by Meehan et al. [31] found that athletes were 17.2 % less likely to return to play within 10 days of a concussive injury when neurocognitive testing was used compared to without (38.5 vs. 55.7 %). In a separate study, researchers reported low correlations between neurocognitive test data and 12–18-year-old athletes estimating their percentage back to normal [39]. This finding suggests that athletes' perceptions of the effects of their injury do not correspond to the actual level of impairment. In summary, computerized neurocognitive test data provide one objective measure of the cognitive deficits associated with concussion that can provide evidence of both impairment and recovery following concussion.

Neuroimaging

In most cases, imaging scans in athletes with a sports-related concussion are not indicated. However, evaluation with computed tomography (CT) or magnetic resonance imaging (MRI) is indicated if a more serious brain injury and/or underlying neuropathology (e.g. subdural haematoma) are suspected. The findings for over 90 % of these CTs and structural MRIs are negative [1]. The use of radioisotope injection-based imaging scans, including single-photon emission computer tomography (SPECT) and positron emission tomography (PET), may be included to assess cerebral blood flow and brain glucose levels if desired. However, these modalities are not yet clinically validated.

Magnetic resonance imaging-based techniques have been a focus of neuroimaging research in patients with concussion and include both functional MRI (fMRI) and diffusion tensor imaging (DTI). Functional MRI utilizes the performance of specific tasks while the subject is in the scanner to detect changes in blood oxygenation, thereby evaluating neural activity. Researchers have reported fMRI and DTI findings in patients with concussion. Lovell et al. evaluated fMRI scans in athletes with sports-related concussion and reported increased activation on fMRI during the first week of recovery predicted protracted clinical recovery [26]. Diffusion tensor imaging measures the movement of water within the brain and facilitates evaluation of the white matter fibre structure, the parameters, and appearance of which can be altered after sports-related concussion. Most researchers have reported a decrease in fractional anisotropy (FA), a measure of white matter integrity or density in the brain, in addition to increase in mean diffusivity (MD), a measure of the average magnitude of diffusion, following concussion [21, 43]. However, other researchers have reported increased FA and decreased MD in the more chronic phases of concussion [15, 27]. These equivocal findings highlight the fact that fMRI, DTI, and other emerging neuroimaging modalities are not yet established or validated for the clinical assessment and monitoring of recovery of athletes following sport-related concussion. Until these modalities are clinically validated, their use remains limited to research purposes.

Conceptualizing treatment using clinical trajectories

Emerging clinical trajectories

Concussion is a complex injury that can involve many different symptoms, impairments, and recovery trajectories. Traditionally, concussion symptoms have been categorized into four discrete symptom clusters: cognitive, emotional, physical, and sleep [35]. A 2012 factor analysis of the PCSS revealed new symptom clusters that were not necessarily discrete entities [20]. As mentioned earlier, post-injury symptoms within the first 7 days of injury are grouped into a primary cognitive-fatigue-migraine global factor along with secondary emotional, physical, and sleep factors. This global symptom factor demonstrated strong cross-loadings on all other factors, suggesting that a patient may not be easily categorized by symptomatology during this first week post-injury. However, the authors intimate that the global factor delineates into more discrete symptom clusters beyond 7 days post-injury. Clinically, this translates into seeing a patient within the first 7 days of injury when they experience more global deficits and

Fig. 2 Clinical trajectories for sport-related concussion

symptoms and then reassessing the patient after this critical period to determine the clinical trajectory of symptoms. Collective clinical and anecdotal evidence indicates that the initial global concussion factor may evolve into specific clinical trajectories, including cognitive/fatigue, vestibular, ocular motor, post-traumatic migraine, affective, and cervical (see Fig. 2).

This new, individualized approach to conceptualizing sport-related concussion is overdue. By conceptualizing clinical trajectories following concussion, rather than the typical homogeneous approach, clinicians can develop more individualized treatment plans and more targeted rehabilitation strategies. A closer examination of the clinical trajectories for each injured athlete reveals specific clinical and symptom presentations, assessment techniques, and treatment protocols that are matched to each trajectory. Although an athlete's injury may manifest into a predominant clinical trajectory, athletes will often present with overlapping clinical trajectories. Consequently, it is important to identify the underlying mechanisms for each involved clinical trajectory to allow for a more comprehensive, yet targeted rehabilitation protocol. A review of the characteristic symptoms, impairments, and each clinical trajectory is provided in the following sections.

Cognitive/fatigue trajectory

The cognitive/fatigue trajectory is typically characterized by symptoms including fatigue, decreased energy levels, non-specific headache, and potential sleep disruption, usually experienced as an increase in symptoms towards the end of the day. The patient whose symptoms fit the cognitive/fatigue trajectory will often have difficulties concentrating and may describe an increased headache with cognitive activity. It is important for the clinician to ask specific questions designed to determine the nature of symptoms, as well as the daily course and onset. Questions such as "does your headache increase as the day progresses" and "do you feel more tired at the end of the day than normal" will guide the interviewer in assessing this trajectory. Questions regarding perceived difficulties concentrating, or focusing on school/work projects, will also provide important clinical information.

A patient who fits the cognitive/fatigue trajectory may present with a normal vestibular/ocular motor screening, if there is no overlap with additional clinical trajectories. Computerized neurocognitive testing typically reveals mild global deficits across memory, processing speed, and reaction time. It is not uncommon to have a patient perform optimally in the clinic setting and then struggle to maintain that performance in the classroom, due to a number of complicating factors, including environmental distractions and time demands.

Targeted treatment and rehabilitation for cognitive/fatigue trajectory

A typical treatment plan for the patient fitting the cognitive/fatigue trajectory includes reducing demands from both a cognitive and physical perspective. In addition, it is important to stress behavioural regulation. For example, the patient should have a regulated sleep schedule that includes a consistent bedtime and regular waking time, even on the weekends. In addition, it is important for the patient to regulate diet, hydration, stress, and exercise in the form of at least one daily walk. It is common for these patients to undergo pharmacological treatment in the form of neurostimulants, particularly amantadine [3]. Sleep aids (e.g. melatonin, zolpidem, and eszopiclone) are utilized when appropriate, particularly when the patient presents with a disrupted sleep schedule or is unable to initiate sleep. In more protracted cases, cognitive/speech therapy may also be indicated.

Vestibular trajectory

The vestibular trajectory is typically characterized by symptoms including dizziness, fogginess, nausea, a feeling of being detached, anxiety, and overstimulation in more complex environments. These patients will often describe an increase in symptoms when in busier, more stimulating environments (i.e. grocery stores and high school cafeterias). Rapid head or body movements may exacerbate symptoms. In assessing for vestibular dysfunction, it is important to consider all environments in which the patient is exposed. For example, patients may report an increase in vestibular symptoms while in school or at work, with a decrease when at home. It is important to note triggers for a vestibular reaction, as well as what activities do not provoke a vestibular response. For some patients, this will include activities as mundane as rolling over in bed (which may indicate a peripheral vestibular aetiology), whereas others will only be provoked when running or riding in a motor vehicle (which may indicate a central vestibular aetiology).

A comprehensive vestibular/ocular motor screening is essential in assessing the vestibular trajectory. Often, this screening will reveal provocation of symptoms with horizontal and/or vertical gaze stability and optokinetic sensitivity. These patients may or may not present with balance difficulties. Neurocognitive test data may include overall deficits in processing speed and reaction times, with relatively intact memory performance.

Targeted treatment and rehabilitation for the vestibular trajectory

The cornerstone of treatment for the vestibular trajectory is comprehensive vestibular therapy. It is of utmost importance that the vestibular therapist is trained specifically in neuro-rehabilitation and is able to design an individualized treatment plan based on the patient's current presentation. In some cases, patients will experience emotional changes secondary to the vestibular response. In these cases, pharmacological intervention may be warranted. Likewise, patients with more persistent vestibular dysfunction may experience migraine symptoms triggered by vestibular overstimulation, or dysregulated sleep. A consultation with a medication provider may be warranted in these cases as well.

Ocular motor trajectory

The ocular motor trajectory is typically characterized by symptoms including localized, frontally based headaches, fatigue, distractibility, difficulties with visually based classes, pressure behind the eyes, and difficulties with focus. These patients may report difficulties with extended time in front of computer screens or while reading. Full days of school or work may intensify symptoms, with an overall decrease in symptoms over the weekend. It is important to assess for quality of headache, as well as location. For example, is the headache characterized by a frontal pressure sensation or behind the eyes? Is headache exacerbated by extended time reading or working on the computer? It is also important to assess for blurred or double vision. Sometimes patients will report difficulty seeing the board in school, or reading text on the television. As noted, students may have more difficulties in visually based classes, such as math and science.

Although the vestibular/ocular motor screening may reveal difficulties with all ocular motor movements (i.e. smooth pursuits and saccadic eye movements), it is more likely that ocular motor dysfunction will be evidenced with abnormal near-point convergence and/or accommodation measurements. Neurocognitive test data may include deficits in visual memory and reaction time. Regarding memory performance, it is likely that there will be evidence of decreased encoding, rather than retention of information.

Targeted treatment and rehabilitation for ocular motor trajectory

There are several avenues for rehabilitation for patients with ocular motor dysfunction. If available, a comprehensive evaluation by a specifically trained neuro-optometrist or other vision therapy provider is preferable. However, if this type of evaluation is not available, vestibular therapists should be able to evaluate and began treatment for patients with ocular motor dysfunction. If the presenting problem is a convergence insufficiency, vestibular therapy may be adequate. However, with more complex presentations, the involvement of a vision therapy specialist is warranted. During rehabilitation, it is important to reduce strain on the visual system. Athletes who are in school may request audiobooks to reduce reading requirements, whereas adult athletes may require frequent breaks from computer work. When treating a patient with ocular motor dysfunction, it is important to remember that isolated binocular vision dysfunction will not typically impede the patient's ability to engage in aerobic-based physical exertion. Therefore, a dynamic (i.e. lateral, head, sport-specific movements) physical exertion protocol may be initiated while the patient continues to rehabilitate the ocular motor system.

Anxiety/mood trajectory

The anxiety trajectory is typically characterized by an overall increase in anxiety, including ruminative thoughts, hypervigilance, feelings of being overwhelmed, sadness, and/or hopelessness. Patients presenting with anxiety may also report sleep disturbance that is sometimes caused by an inability to quiet their minds, or simply stop thinking and worrying. It is also important to assess for any personal or family history of anxiety. Oftentimes, patients will be unable to accurately identify or characterize feelings of anxiety, as the symptoms of anxiety manifest through headache, feeling "foggy", dizzy, or fatigued. Asking patients how much time they spend thinking about their injury and current symptoms may shed some light on the presence of underlying anxiety. If symptoms are occurring during downtime (e.g. sitting in bed or being alone) and without vestibular influence (e.g. during movement and activity), anxiety may be considered. Careful investigation regarding sleep disturbance may also help disentangle anxiety-related from other sleep disturbances.

The vestibular/ocular motor screening may be mildly provocative in patients in the anxiety/mood trajectory if there is a concurrent vestibular component to their injury. However, in cases with a personal or family history of anxiety, the vestibular/ocular motor screening may be non-provocative. If vestibular involvement is detected, this must be addressed prior to treating the anxiety. In some cases, alleviating the vestibular symptoms will facilitate a decrease in anxiety independent of specific targeted treatments. If no vestibular contribution is detected, neurocognitive test data may be within normal limits.

Targeted treatment and rehabilitation for anxiety/mood trajectory

Once any identified vestibular symptoms have resolved, supervised physical exertion protocols should begin. For athletes with any emotional contribution, whether anxiety, depression, or simply irritability, increased exertion is a critical treatment component. Increased exertion will not only serve as an emotional release, but may help to decrease overall arousal level. Providing these patients with a daily exercise plan and having them track their progress will help refocus their attention and will likely help to speed recovery. In addition to regular exercise, incorporating a regulated sleep schedule, with consistent diet, hydration, and stress management is crucial. Patients with anxiety often do better when provided with structure and this type of regimented schedule will help to regulate autonomic functioning and again, speed recovery. When these strategies are not successful, or when the underlying anxiety is not diminishing at the expected rate, it may help to refer these patients for psychotherapy or initiate pharmacological intervention.

Post-traumatic migraine trajectory

The International Headache Society defines a post-traumatic migraine as a unilateral, moderate to severe intensity headache following a head trauma with a pulsating quality that is associated with nausea and photosensitivity and/or phonosensitivity and is often aggravated by physical activity [14]. Patients who are conceptualized within the migraine trajectory typically experience this type of headache intermittently, although in more severe cases, the headache may be chronic and consistent. Migraine symptoms are often exacerbated by increased stress, sleep dysregulation, anxiety or emotional changes, and dietary triggers such as caffeine. When evaluating these patients, it is important to investigate personal and family history of migraine. The vestibular/ocular motor screening may be non-provocative if there is no vestibular or ocular motor component. However, neurocognitive test data will often reveal memory deficits that may be verbal or visually based.

Targeted treatment and rehabilitation for post-traumatic migraine trajectory

The most common treatment recommendations for individuals with migraine include pharmacologic intervention in the form of tricyclic antidepressants, anticonvulsants, beta blockers or calcium channel blockers (as preventative), or triptans (as abortive). In addition, increased cardiovascular activity is recommended and initiation of a supervised exertion protocol is highly recommended. As with the anxiety trajectory, a regulated schedule in terms of sleep, diet, hydration, exercise, and stress management can be very useful and should be encouraged.

Cervical trajectory

There is a subset of patients whose presentation is largely cervicogenic in nature. These patients will typically present with headache and neck pain and may not fit the other clinical trajectories in terms of vestibular/ocular motor or neurocognitive deficits. When assessing for this trajectory, it is important to focus on characterization of the headache (i.e. dull, throbbing, pressure), as well as location (i.e. frontal, temporal, occipital). Asking about the onset and course of daily headaches will help to identify triggers. Directly asking about neck pain or numbness and tingling of the extremities will provide more information as well. When cervical involvement is suspected, a careful assessment by a certified physical therapist is warranted. This assessment typically includes cervical range of motion (ROM), strength evaluations, testing for cervical ligamentous instability, and assessment of cervical musculature flexibility.

Targeted treatment and rehabilitation for cervical trajectory

Management of the cervical trajectory includes ROM exercises, manual cervical and thoracic mobilization, soft tissue mobilization, posture re-education, biofeedback, modalities as warranted for pain management, and trigger point injections. In addition, pharmacological interventions include analgesics, anti-inflammatories, and muscle relaxants, may be warranted in more protracted cases.

Interdisciplinary team

Given the heterogeneous nature of sport-related concussion, this injury cannot be assessed and a managed in a vacuum. In short, it “takes a village” to manage the clinical care for this injury. As such, sport medicine teams should leverage interdisciplinary expertise to identify, assess, manage, and treat the various clinical trajectories of concussion. This approach should involve a centralized clinician with appropriate training and expertise in concussion care (e.g. clinical neuropsychologist) who serves as the conduit through which the clinical care of this injury is coordinated and monitored. It is important to note that the central role of the neuropsychologist in this model could be served by a number of qualified individuals including orthopaedic surgeons and primary care sports medicine physicians. This provider then coordinates, refers, and manages the overall care of the injured athlete from comprehensive assessment through to return to play. Ideally, this approach should involve an interdisciplinary team of experts that reflects the heterogeneity (i.e. clinical trajectories and treatment pathways) of this injury (see Fig. 3). Once an athlete has undergone an initial evaluation, a number of referrals for both assessment and treatment may be made, including vestibular therapy, vision therapy, primary care sports medicine, physical medicine and rehabilitation (PM&R), exertion therapy, neuroradiology, or neurosurgery. This team approach will allow sports medicine professionals to create a clinical care network that can effectively assess and treat the myriad issues associated with sport-related concussion.

Return to play guidelines

In addition to identifying targeted treatment pathways based on an individual’s specific clinical trajectory and leveraging an interdisciplinary team’s expertise, it is important for clinicians to follow a standardized return to play (RTP) exertion protocol. The most important component to any RTP decision process is that athletes with any signs, symptoms, or impairment from a suspected concussion should not be allowed to RTP. In other words, “when in doubt sit them out”, is the best policy to minimize potential adverse effects from returning an athlete to play too soon. The current International Consensus Statement identifies the need for a graduated RTP protocol that includes a stepwise progression in which an athlete may progress to the next level only when asymptomatic at the current level [29]. Most RTP models indicate that all patients start at Stage 1 and spend at least 24 h at each

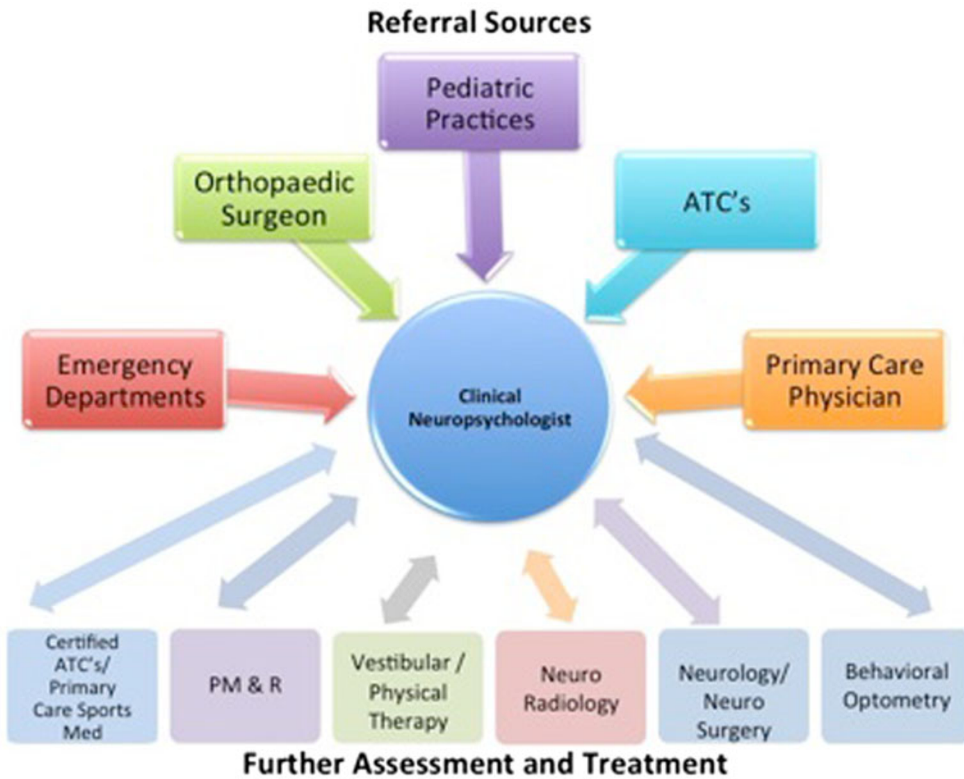

Fig. 3 Interdisciplinary concussion team

stage before progressing to the next stage [29]. However, this approach assumes that concussion recovery trajectories are homogenous and linear in nature and may therefore represent a somewhat outdated conceptualization. For example, if an athlete is injured and presents as symptom free with neurocognitive test scores at baseline levels only 2 days from the time of injury, he or she may not need to begin at Stage 1 exertion. In this case, the physical therapist or athletic trainer working with the athlete may be able to progress the athlete through several stages in 1 day without provocation of symptoms. As such, the RTP protocol should be a more fluid process, with subjective report of symptoms dictating the discontinuation point. However, it is important to note that researchers have reported that symptom reporting alone may not be the most effective approach to assessing RTP following exertion [30]. These researchers found that nearly 1/3 of athletes who were symptom free following exertion failed at least one neurocognitive test, indicating that post-exertion neurocognitive testing may be warranted if a clinician suspects a patient is not accurately or honestly reporting symptoms. Regardless of the length of time required to complete the RTP protocol, it is still recommended that athletes progress in a stepwise fashion, beginning with light aerobic exercise and progressing through sport-specific movements, light contact drills, and a final, full-contact practice.

Given the important role of the vestibular system following concussion, it is also recommended that clinicians incorporate dynamic (i.e. lateral, head and sport-specific), plyometric-based movements that could provoke underlying vestibular symptoms or dysfunction. There are times when an athlete, who may appear normal on the VOMS at rest, has a return of vestibular and other symptoms following dynamic movements that often mimic the sport in which they participate. If this type of exertion is not utilized, this provocation of symptoms may go undetected and the athlete could potentially be returned to play and exacerbate their vestibular symptoms and dysfunction and lengthen their recovery. Physical therapists and athletic trainers trained to perform the RTP protocol should be trained in assessing potential vestibular symptoms and dysfunction (e.g. using the VOMS) and develop the appropriate recommendations based on this assessment. Typically, when vestibular involvement is detected, a short course of vestibular therapy, or extended exertion therapy, is the most effective course of treatment.

This proposed used of dynamic exertion extends the current standard of practice and based on clinical experience when the RTP protocol includes this extra step reduce recidivism in patients and ensures a safer and more informed RTP. Undetected vestibular and ocular motor deficits suggest that the brain is not fully healed and may therefore make athletes more susceptible to additional injuries. When considering athletic retirement, clinical experience supports that the implementation of a more comprehensive RTP protocol can significantly reduce the number of athletes required to retire from sports due to concussion-related concerns. When developing treatment and RTP plans that are based on clinical trajectories, rather than a homogenized approach, each patient is conceptualized individually, which leads to targeted and more effective approaches to RTP. This model helps to facilitate complete recovery prior to clearance for RTP. This shift in thinking may not only change the way concussion is conceptualized, but may also shape the way in which treatments are implemented.

Conclusion

Sport-related concussions are heterogeneous and require an individualized clinical approach. However, past clinical approaches (i.e. grading scales) focus on a homogenous, "one size fits all" framework from which to conceptualize and treat concussion. The use of a comprehensive, interdisciplinary approach for assessing specific clinical trajectories following a sport-related concussion presented in this paper will help clinicians better conceptualize this highly individualized injury. Clinicians can then match targeted treatment pathways to specific clinical trajectories to accelerate safe RTP for athletes following a sport-related concussion.

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