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Original article

Concussion - Part I: The need for a multifaceted assessment

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ABSTRACT

Introduction: Concussion is among the most commonly occurring sport and recreation injuries in today's society. An understanding of the heterogenous nature of concussion will assist in directing a multifaceted and comprehensive interdisciplinary assessment following injury.

Purpose: The purpose of this masterclass article is to summarize the current state of the evidence in the area of concussion, describe typical symptom presentations and assessment techniques that may assist in directing appropriate management following concussion.

Implications: A comprehensive assessment including a thoughtful differential diagnosis will assist the clinician to direct care appropriately and efficiently in individuals who have suffered a concussion.

1. Introduction

Concussion is a common injury in today's society (Marar et al., 2012). An estimated 1.6–3.8 million sport-related concussions per year occur in the United States (Feigin et al., 2013; Langlois et al., 2006). Many published estimates of concussion incidence likely underestimate the true burden, as most are based on hospital data and represent only the more severe end of the spectrum. Studies evaluating the risk of concussion in youth and collegiate sport have found that concussions account for over 15% of the overall injury burden, with the highest risk reported in contact and collision sports and during competitive play compared to training(Emery et al., 2017; Emery et al., 2006; Emery and Tyreman, 2009; Kerr et al., 2017; O'Connor et al., 2017; Schneider et al., 2018b; Zuckerman et al., 2015). Even with this underreporting, concussion remains one of the most common injuries in sport and recreation today(Emery and Meeuwisse, 2006; Zuckerman et al., 2015).

For the purposes of this Masterclass article, the definition of concussion from the 5th International Consensus Statement on Concussion in Sport as summarized below will be used(McCrory et al., 2017a, McCrory et al., 2017). Concussion is a brain injury that results from a traumatic blow to the head or body with subsequent force transmission to the head. Concussion is usually a functional rather than structural injury to the brain (McCrory et al., 2017). Standard neuroimaging (CT and MRI) findings are typically normal.(McCrory et al., 2016) Newer functional imaging techniques are emerging, but require further evaluation before their routine use(McCrea et al., 2017). No one test diagnoses a concussion, rather the diagnosis involves an individualized multifaceted clinical assessment (e.g. symptom reports, neurological screen, balance, visual, vestibulo-ocular, cervical spine and cognitive assessment).(Feddermann-Demont et al., 2017; Patricios et al., 2017).

Concussions do not present the same way in every person and, thus, a multifaceted assessment is recommended(Feddermann-Demont et al., 2017; Schneider, 2016). Given this heterogenous nature of concussion, an interdisciplinary approach including a variety of health care professionals is warranted. Depending on the environment (rural vs urban; high performance sport vs grass roots sport), available health care resources and the local scope of practice regulations for each health care professional, a collaborative team approach including sport-medicine physicians, physiotherapists, family physicians, neurologists, neuropsychologists, athletic therapists and others will be engaged and work together to optimize care (see Fig. 1). Physiotherapists are an integral part of the interdisciplinary team and possess a unique skillset that can inform recognition of concussion on the field of play, inform differential diagnosis of concussion, early management, re-evaluation and rehabilitation of physical ramifications of concussion across the continuum of care in the clinic and facilitate return to sport and school. The precise role of the physiotherapist may vary between locations and will depend on the expertise and competency that the physiotherapist has in each context (i.e. sport physiotherapist vs. expertise in vestibular rehabilitation vs. manual therapy). Working collaboratively with the treating physician and other health care professionals will ensure a coordinated and comprehensive approach to care.

The purpose of this Masterclass article is to summarize the assessment of concussion, including: the current state of the evidence in concussion, describe typical symptom presentations and assessment techniques that may assist in directing appropriate management in the acute and follow-up phases after a concussion. The acute assessment is focused on recognizing the potential of a concussion or more serious

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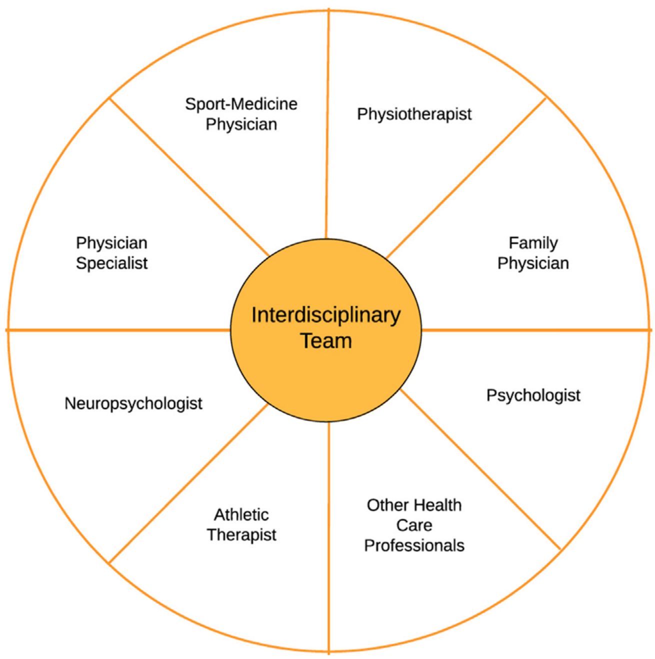

Fig. 1. Interdisciplinary team in the assessment and management of concussions.

injury. Assessment in the later stages following injury is focused on an interdisciplinary assessment to direct differential diagnosis and management. Initial management and rehabilitation strategies are outlined in Part II and an online case study is presented to summarize these concepts in practice.

2. Acute assessment of a suspected concussion

Concussion can occur secondary to a direct trauma to the head or following a blow to another part of the body with force subsequently transmitted to the head.(McCrory, Meeuwisse, 2017b) To date, there is no set magnitude of impact or mechanism that can identify when a concussion has occurred. At the time of concussion, there may or may not be reports of a loss of consciousness (LOC is only reported in less than 10% of concussions (Marshall et al., 2015)) or other signs of altered function (e.g. unsteadiness, looking dazed or confused, clutching the head).(McCrory et al., 2016) Symptoms may present immediately following a concussion or they may evolve with time, typically within 24 h of injury(McCrory et al., 2013). A concussion can result in a myriad of symptoms, the most common of which is headache(Kerr et al., 2016). Other common symptoms include dizziness, fatigue, difficulty concentrating, difficulty remembering, difficulty falling asleep, neck pain, irritability and feeling as if being in a fog(Marshall et al., 2015). A concussion should be suspected when one or more symptoms, physical signs, balance impairment, behavioural changes, cognitive impairment or sleep disturbance is present.(McCrory et al., 2016) It is important to educate all stakeholders (i.e. parents, coaches, officials, players, teachers, sport administrators, etc) to the potential symptoms and signs that may occur following a concussion so that proper assessment and management can be immediately implemented and the player/athlete is removed from an environment in which there is ongoing risk of injury and potential for a second impact. The Concussion Recognition Tool 5 (CRT5) is meant for all stakeholders to use when observing for a suspected concussion, whereas the Sport Concussion Assessment Tool 5 (SCAT5) and Child SCAT5 are meant to be used as screening tools for health care professionals in the sideline or acute assessment of concussion. Symptom provocation and assessment of oculomotor and vestibulo-ocular function may be useful screening tests used as part of the clinical examination in the subacute time period. These tools are summarized in the following section.

2.1. *The Concussion Recognition Tool 5 (CRT5)*

The Concussion Recognition Tool 5 (CRT5) was developed to assist with the process of "recognize and remove" and is meant for use by lay personnel to assist with recognition of potential concussions and gives recommendations for initial management(Echemendia et al., 2017c). This tool is an evolution of the previous Pocket Sport Concussion Assessment Tool 2 (Pocket SCAT2) and the Pocket Concussion Recognition Tool (Pocket CRT) that were published by the Concussion in Sport Group following the 3rd and 4th International Consensus Conferences on Concussion in Sport respectively(McCrory et al., 2009; McCrory et al., 2013). The CRT5 now includes a sequential process of assessment. Step 1 is to recognize red flags (e.g. weakness or tingling/burning in the arms or legs, severe or increasing headache, seizure or convulsion, deteriorating conscious state). If red flag signs are present, it is recommended that an ambulance is called. Provided no red flags are present, the observer would then move to step 2 and look for signs that suggest a concussion may have occurred. The signs listed include balance difficulties, blank or vacant look, slow to get up, laying motionless, disorientation, etc. Step 3 is a report of symptoms that may occur following concussion. Step 4 is performed for athletes over the age of 12 and includes a series of five questions related to the sport event at which they are. An inability to answer these questions correctly may suggest a concussion. Recommendations for the athlete/player to be monitored for the initial few hours following injury (not be left alone or sent home on their own), avoidance alcohol, avoidance of recreational drugs and driving a vehicle are given. This tool is not meant as a diagnostic tool, but rather to assist with recognition of possible concussions by the lay public(Echemendia, Meeuwisse, 2017c). The CRT5 is freely available (https://bjsm.bmj.com/content/51/11/872) and may be copied and distributed to all individuals who may be involved in activities where concussions could occur.

A key component to the initial screen following concussion is to ensure that a more serious injury, such as an intracranial injury, spinal cord injury or cervical spine fracture, has not occurred. Clinical decision rules such as the Canadian CT head rules and the Canadian C-Spine rules may be applied to screen for the need for further imaging for the head and/or neck(Stiell et al., 2001a, 2001b). The Sport Concussion Assessment Tool 5 (SCAT5) was developed for health care professionals to use on the sideline as a screening tool for concussion(Echemendia et al., 2017b). This multifaceted assessment tool has been reported to have good clinical utility as a screening tool in the initial (3–5) days following concussion, however beyond this point the clinical utility of the SCAT5 as a screening tool degrades(Echemendia et al., 2017a; Patricios et al., 2017). The SCAT5 is intended for use by health care professionals as part of a standardized assessment of concussion that facilitates a multifaceted assessment but *should not be used as the sole method* to inform clinical decisions(Echemendia, Meeuwisse, 2017b).

2.2. *Sport Concussion Assessment Tool 5 (SCAT5)*

The initial version of the SCAT was developed following the 2nd International Consensus Conference on Concussion in Sport(McCrory et al., 2004). The initial purpose was to provide a standardized tool for physicians to use in the assessment of concussion (by bringing together eight previously existing tools) as well as providing education for patients(Davis et al., 2017b). This tool has subsequently evolved following each of the 3rd, 4th and 5th consensus conferences on concussion in sport with key elements remaining the same but evolving with the literature(Echemendia, Broglio, 2017a; Echemendia, Meeuwisse, 2017b; Guskiewicz et al., 2013; McCrory et al., 2009). A variety of subgroups of tests that evaluate specific functions are included in the SCAT5 and were divided into an immediate or on-field assessment and a follow-up office assessment portion(Echemendia, Meeuwisse, 2017b). The immediate or on-field assessment of concussion includes screening for red flags, recording of observable signs, Maddocks questions (memory assessment), the Glasgow coma scale (GCS) and a brief cervical spine screen. The office assessment portion of the SCAT5 includes a history, symptom reports (22 item Post Concussion Symptom Scale), cognitive assessment [Standardized Assessment of Concussion (SAC)], neurological screen and balance examination [using a modified Balance Error Scoring System (BESS) (total score is 30)] (http://www.sportphysio.ca/wp-content/uploads/SCAT-5.pdf) (Echemendia, Meeuwisse, 2017b)

Due to the developmental differences in children as compared to adults, the Child SCAT5 was created for use in children and youth aged 5–12 years (https://bjsm.bmj.com/content/bjsports/early/2017/04/28/bjsports-2017-097492childscat5.full.pdf).(Davis et al., 2017a; Davis, Purcell, 2017b) The Child SCAT5 has many similarities to the SCAT 5, however symptoms on the Child SCAT5 are measured using the Health and Behavior Inventory (HBI) that includes both child and parent reports(Ayr et al., 2009).

A comparison of symptoms reported on the Child SCAT3 and SCAT3 by 10–12 year olds identified that neck pain was one of the most commonly reported symptoms in this age group, however there was no corresponding neck pain measure on the Child SCAT3 symptom scale (Black et al., 2017). Thus, neck pain ratings were added to the Child SCAT5 symptom scales(Davis, Purcell, 2017b). Additional changes to this version of the Child SCAT5 that are different from the SCAT5 include removal of the orientation questions and the addition of a neurological screen that includes a photograph for younger children to describe if they are not yet able to read(Davis, Purcell, 2017b). It is important to recognize that while the SCAT5 and Child SCAT5 can be used as screening tools and as part of the multifaceted assessment, they are not meant to replace an individualized multifaceted clinical exam (Echemendia, Meeuwisse, 2017b).

2.3. *Vestibular and oculomotor assessments as screening tools for concussion*

The Vestibular/Ocular Motor Screen (VOMS) is a brief screen that asks patients to report symptom changes (for headache, dizziness, nausea and fogginess) during five different tests: smooth pursuit, horizontal and vertical saccades, near point of convergence distance (NPC), horizontal vestibular ocular reflex and visual motion sensitivity(Mucha et al., 2014). For convergence, both change in symptoms and distance for near point of convergence are recorded and averaged across three trials (normal is considered to by < 5 cm). The VOMS has been shown to be able to screen for concussion at the time of clinical follow-up (5.5 days ± 4.0 days following concussion; range = 1–21 days)(Mucha et al., 2014). However, it is important to note that symptom reproduction does not necessarily align with clinical abnormalities on this test(Sharma et al., 2018).

A combination of signs and symptoms during optokinetic stimulation, gaze stabilization test (defined as horizontal head rotations 30° each way at a speed of 240 beats per minute for 1 min) and near point of convergence have been reported to have high discriminant ability between healthy controls and athletes in the subacute time period following a concussion (2–10 days) (accuracy = 94.4%, AUC = 0.95) (McDevitt et al., 2016). Additional screening tools can be used to suggest that a concussion may have occurred but should not replace the multifaceted clinical examination.

3. Assessment of individuals who have ongoing symptoms past the initial 7–10 days following injury

The majority of individuals who suffer a concussion will recover in the initial 10–14 days(Marshall et al., 2015, McCrory et al., 2016). However, 20–30% of children and youth may have ongoing symptoms 4 weeks following injury(Schneider, Nettel-Aguirre, 2018b; Zemek et al., 2016). Individuals who report high symptom intensities acutely following concussion, those with vestibulo-ocular dysfunction and cervical spine involvement may take longer to recover following concussion(Ellis et al., 2015, 2019; Iverson et al., 2017).

For individuals who have ongoing symptoms, a comprehensive evaluation is undertaken after a suspected concussion and includes symptom reports, a neurological screen (including balance and coordination assessments), assessment of the cervical spine, balance, vestibulo-ocular, visual systems, mood and a neurocognitive screen (Broglio et al., 2007; Feddermann-Demont et al., 2017; Schneider et al., 2018a). Historically, neurocognitive evaluation has received wide attention because of reports of memory disturbances and challenges with information processing following injury. In recent years, evidence suggests multiple domains may be affected, including vestibular, balance, visual systems and the cervical spine(Feddermann-Demont et al., 2017). Of interest, clinical findings of persons presenting to a subspecialty clinic following a sport-related concussion indicate cervical and vestibular involvement in up to 85% of youth and adults (MacGregor et al., 2017). Thus, a detailed multifaceted assessment, based on the individual's clinical presentation is required(Makdissi et al., 2017; Schneider, 2016). In the majority of cases it is not just one symptom that persists, but a number of symptoms (Fig. 3). Symptoms alone cannot differentiate between mechanisms of dysfunction. Thus an assessment that evaluates different aspects of function and systems that could be affected following a concussion is important in the differential diagnosis in the presence of ongoing symptoms(Leddy et al., 2015).

A thoughtful differential diagnosis including a thorough history followed by a detailed clinical examination can assist in directing appropriate management. The assessment should include a neurological screen (including a cranial nerve scan and tests of cerebellar function, long tract signs, reflexes, key muscles, dermatomes). Provided no alarming signs are present, further assessment tests that include evaluation of cervical spine, motor control, vision, vestibular and physical exertion can be used to direct management(Feddermann-Demont et al., 2017; Leddy et al., 2015; Master et al., 2018; Schneider, Meeuwisse, 2018a) (See Fig. 4).

3.1. *Posttraumatic headache*

Headache is consistently one of the most common symptoms following sport-related concussion and can affect 40–86% of individuals who have suffered a concussion(Kerr et al., 2016; Lucas et al., 2014). To be defined as a posttraumatic headache, headache onset must be within 7 days of trauma(Lucas, 2015). In some individuals, dizziness accompanies headache and balance deficits may be evident.(Necajauskaite et al., 2005; Register-Mihalik et al., 2008).

Different post-traumatic headache types have been reported following concussion(Lucas, 2015). Migrainous symptoms, including photophobia, phonophobia, nausea, dizziness and neck pain, have been reported in individuals with post-traumatic headaches (PTH)(Heyer et al., 2016). Persisting PTHs are variably reported as migraine or probable migraine, tension-type headaches, cervicogenic headaches, occipital neuralgia and medication overuse headaches(Lucas, 2015; Lucas et al., 2014; Pinchefsky et al., 2015; Zasler, 2015).

3.2. *Cervical spine involvement*

Neck pain is common following concussion(Benson et al., 2011; MacGregor et al., 2017). It is certainly conceivable that the cervical spine may be injured at the time of a concussion given the traumatic nature of this injury. Many symptoms of concussion are similar to those reported by individuals who have suffered a whiplash injury (Elkin et al., 2016; Hynes and Dickey, 2006; Morin et al., 2016) and parallels to whiplash associated disorders, chronic neck pain and cervicogenic headaches are observed in individuals with persisting neck pain following concussion(Hynes and Dickey, 2006). Clinical findings suggesting cervical spine involvement have been identified in individuals presenting to physiotherapy clinics and sport medicine centres for assessment following concussion(Ellis et al., 2019; Kennedy et al., 2017; MacGregor et al., 2017; Schneider et al., 2014b).

It is important to consider the cervical spine following concussion to confirm or negate its involvement. The upper cervical spine has a major proprioceptive role and alterations in cervical afferent input may result in cervicogenic dizziness, often described as light headedness, a sensation of feeling "off" or in a fog(Kristjansson and Treleaven, 2009; Treleaven, 2008; Treleaven et al., 2003). These symptoms are similar to those reported following concussion. Importantly, cervical involvement does not "rule out" a concussive injury but instead suggests that there may be concurrent injury to the cervical spine and brain. A thorough assessment of the cervical spine is necessary from a movement, neuromuscular and sensorimotor control standpoint(Kristjansson and Treleaven, 2009; Schneider et al., 2017b). The myofascial system may also be a source of headaches and/or neck pain(Lluch et al., 2015). Painful trigger points are the salient feature of myofascial pain syndrome and are commonly reported in the upper trapezius, scalenes and suboccipitals in individuals with cervical spine pain(Lluch et al., 2015; Sacena et al., 2015). In some cases painful trigger points can occur in migraine and tension type headaches and do not necessarily implicate the cervical spine.

3.3. Manual spinal exam

A cervical spine exam including an extension rotation test (ER), palpation for segmental tenderness (PST) and manual spinal exam (MSE) can be used to detect the presence or absence of suspected cervical facet joint dysfunction in individuals with ongoing neck pain(Jull et al., 1988; Schneider et al., 2013, 2014a). To perform the ER test, the patient is seated and asked to extend and rotate their head as far as possible(Schneider et al., 2013). To perform the MSE, the patient is positioned in prone and a posterior-anterior force over the articular pillars from C2-3 to C6-7 is performed and any limitation to motion is rated as normal, slight, moderate or marked. To perform the PST, the assessor palpates the segmental muscles that overly the facet joints from C2-3 to C6-7(Schneider et al., 2013). For all three tests, a positive test occurs when familiar pain of 3/10 or greater is reproduced and, for MSE, resistance to motion is rated as moderate or marked(Schneider, Jull, 2014a). A positive test on all three is highly predictive of facet joint mediated pain(Schneider, Jull, 2014a).

The cervical flexion rotation test is a test that has been reported to have good diagnostic accuracy for C1/2 related cervicogenic headache (Hall and Robinson, 2004; Ogince et al., 2007). To perform the test, the patient's neck is fully flexed and rotated to the right and left. A reduction of 10° or greater with a firm end feel is considered a positive test(Ogince et al., 2007).

3.4. Motor control

Assessment of the deep cervical flexor muscles can be performed using the Craniocervical flexion test(Jull et al., 2008). To perform this test, the patient is positioning in crook lying with the cervical spine in neutral. A pressure biofeedback cuff is placed in contact with the occiput between the neck and the plinth/towel. It is then inflated to 20 mmHg and the patient is asked to nod as though saying "yes". Progressive increases on the pressure sensor are monitored as the patient works to a maximum of 30 mmHg holding 10 times for 10 s(Jull, O'Leary, 2008). It has been demonstrated that individuals with neck pain disorders have altered neuromotor control strategies compared to controls(Falla et al., 2004; Jull et al., 1999, 2007).

3.5. Cervical flexor and extensor endurance

The cervical flexor endurance test has been reported to be a useful discriminant test for individuals with WAD when compared to uninjured controls. This test is performed in crook lying and the patient performs a craniocervical flexion motion and then lifts the head slightly and holds the position for as long as possible to fatigue or pain(Olson et al., 2006). Assessment of cervical extensor endurance can also be performed in prone with the hands at the side and a band attached to the head with a 2 kg weight suspended(Edmonston et al., 2008, 2011).

3.6. Cervical strength

The cervical rotation side-flexion test has been used to assess strength of the anterolateral cervical flexors. Patients are positioned in supine with their head maximally rotated to one direction and the head is then laterally flexed off of the pillow(Metcalfe et al., 2006).

3.7. Sensorimotor control

Assessment of sensorimotor control of the cervical spine includes a number of different tests, each evaluating a different, yet interrelated function. Joint position error (JPE) is a test that can be used to assess head and neck awareness and evaluates the ability to relocate the head to a neutral position in space(Revel et al., 1991). To perform this test, a laser pointer mounted to the head or a pair of foveal glasses can be used. The patient looks straight ahead (or at a preset target angle) in a natural position, closes their eyes and rotates as far as they can comfortably move and returns to the original position and stops their head motion (i.e. indicating when they perceive they have reached the original starting position). The distance from the original target is then measured. Greater errors (i.e. over 4.5°) in individuals with Whiplash Associated Disorders (WAD) and dizziness compared to individuals without dizziness have been reported(Treleaven et al., 2003). To minimize input from the vestibular system, a newer test of trunk relocation with a stationary head has been proposed(Chen and Treleaven, 2013). Individuals who report feeling as though their head motion is "jerky" may have difficulty with cervical movement control. Computerized programs, stationary patterns and virtual environments have been used to assess control of cervical movement(Oddsdottir and Kristjannson, 2012; Woodhouse et al., 2010).

The smooth pursuit neck torsion test (SPNTT) evaluates smooth pursuit in a neutral cervical spine position compared to a torsioned cervical spine position (trunk is rotated on a stationary neck)(Tjell and Rosenhall, 1998). Abnormalities have been reported in individuals with WAD(Tjell and Rosenhall, 1998; Treleaven et al., 2008). The cervical torsion test has been reported to identify nystagmus of greater than 2°/second in a sustained neck torsion and has been proposed as a test that may be used in the assessment of cervicogenic dizziness(L'Heureux-Lebeau et al., 2014). The addition of the above stated tests to the clinical examination may assist in understanding the cervical contributions to sensorimotor control alterations that are observed following trauma, however future research is needed to understand the clinical utility of these tests in concussion(Cheever et al., 2016; Treleaven, 2017).

The head perturbation test is a newly developed test that assesses the patient's ability to maintain their head in a stationary position while an external force is applied to the head. The patient is positioned in unsupported sitting with the arms crossed on shoulders and eyes closed. The examiner observes for a "bobble", or an inability to maintain a stationary position, when an external force is applied to the head (Schneider, Meeuwisse, 2018a).

While similar patterns to cervical musculoskeletal dysfunction have been observed in individuals with concussion in the clinical setting as found in neck disorders (Schneider, Meeuwisse, 2014b), research in the field is sparse. One exploratory cohort study in youth ice hockey players compared a series of cervical spine measures, preinjury and following a concussion(Schneider, Meeuwisse, 2018a). In the acute time period following concussion, 58% reported an increase in headaches and 42%, an increase in neck pain. Following concussion, the cohort performed significantly worse on measures of cervical spine function, including cervical spine anterolateral flexion strength, cervical flexion rotation test, cervical flexor endurance, head perturbation test and joint position error (left)(Schneider, Meeuwisse, 2018a). Significant changes in measures of vestibulo-ocular function and dynamic balance were not observed(Schneider, Meeuwisse, 2018a). Another study identified upper cervical joint signs and reduced neck flexor endurance in individuals with persistent headache following traumatic brain injury. (Treleaven et al., 1994) An exploratory study in elite rugby players demonstrated increased size and contraction of trunk muscles following concussion compared to preseason assessment(Hides et al., 2017). Thus, there is emerging evidence that a thorough assessment of the cervical spine including assessment of neuromuscular control, sensorimotor control and a manual spinal exam following concussion is warranted to identify potential cervical consequences of concussion (Kennedy et al., 2017; Schneider, Meeuwisse, 2018a, Treleaven et al., 1994).

3.8. Dizziness/balance disorders

Dizziness is a common symptom following concussion and may persist(Schneider, Meeuwisse, 2014b). A thoughtful differential diagnosis is required to identify the source of dizziness and any balance dysfunction as many types of balance disorders may occur following concussion, some of which are most appropriately treated medically and others that are amenable to vestibular rehabilitation(Alsalaheen et al., 2010b, Ernst et al., 2005; Gottshall et al., 2003; van Leeuwen and van der Zaag-Loonen, 2017). Delving into the nature of the dizziness (vertigo, disequilibrium, pre-syncope), duration (seconds, minutes, hours or days), aggravating and easing factors (position changes, movement, etc) and concurrent symptom occurrence is imperative to understanding its potential source. In some cases, vertiginous symptoms may be indicative of more severe injury, such as ischemic stroke involving the cerebellum or brainstem, requiring medical attention(Choi et al., 2017; Kattah et al., 2009; Merwick and Werring, 2014).

Proper orientation in space is achieved through the integration of sensory input from proprioceptive, visual and vestibular receptors (Herdman, 2007). Afferent information from these three peripheral sensory receptors provide input to the central balance system (Armstrong et al., 2008; Guskiewicz, 2001). Multiple complex feedback loops occur between the central and peripheral nervous system before sending efferent output to the extra-ocular and skeletal musculature. (Armstrong et al., 2008; Schubert and Minot, 2004) If one or more of these systems provide inaccurate information about spatial location, alterations in balance and/or dizziness may result with the mismatch of sensory information.

A variety of vestibular disorders may occur following trauma (including Benign Paroxysmal Positional Vertigo (BPPV), labyrinthine concussion, otolith dysfunction, post-traumatic endolymphatic hydrops, post-traumatic migraine, brainstem or vestibulocerebellar dysfunction) as well as cervicogenic dizziness and psychogenic dizziness (Alsalaheen, Mucha, 2010b; Balatsouras et al., 2007; Ellis et al., 2015; Ernst et al., 2005; Herdman, 2007; Hoffer et al., 2004; Schneider, Meeuwisse, 2014b; Zhou and Brodsky, 2015). Many of these conditions respond well to vestibular rehabilitation (BPPV, labyrinthine concussion, cervicogenic dizziness, stable central vestibular disorders).(Hillier and Hollohan, 2007) Other conditions may require medical attention (e.g. where intracranial pressure induced changes result in vertigo or hearing changes, endolymphatic hydrops, migraine or in the presence of findings suggesting a potential central source to symptoms).

BPPV is a biomechanical problem that occurs when debris and/or otoconia becomes free-floating within the endolymph in one of the semi-circular canals (most commonly the posterior semi-circular canal) (Fig. 5).(Balatsouras et al., 2017; Cohen and Sangi-Haghpeykar, 2010) This debris is believed to move more slowly than the endolymphatic fluid with head motion, thus resulting in gravity-induced changes to the position of the cupula (i.e. the debris and/or otoconia continues to move until settling to the most dependent part of the canal) (Bhattacharyya et al., 2017). Thus, a false sense of motion ensues and seconds of vertigo (sensation of spinning) are perceived(Bhattacharyya et al., 2017). Typical motions that provoke symptoms of vertigo in BPPV are bending down, looking up, getting into and out of bed, rolling in bed and fast head movements(Herdman, 2007). A positive test is indicated by a distinct pattern of nystagmus (involuntary eye movement) and concurrent vertigo in the Dix-Hallpike or roll tests. This condition has been reported in approximately 5% of individuals with persistent dizziness following concussion(Alsalaheen et al., 2010a; Schneider, Meeuwisse, 2014b).

Some individuals present with findings suggesting peripheral vestibular hypofunction (i.e. an inability or decreased ability of the peripheral vestibular apparatus to sense motion).(Maskell et al., 2006) A mismatch in afferent input between the two labyrinths (right and left) is believed to occur, however the pathophysiology and mechanism is not well understood. Initially following trauma, these individuals report a sense of vertigo and unsteadiness. As they gradually recover, symptoms change to sensations of dizziness or lightheadedness with faster head motions or in more challenging balance environments. Clinical findings consistent with a unilateral peripheral vestibular hypofunction may be present including specific patterns of nystagmus, alterations in vestibulo-ocular reflex (VOR) function (vestibular labyrinth input directs the eyes in an equal and opposite direction to that of the head to enable stable gaze with rapid head motion), static and dynamic balance deficits in addition to sensitivity to motion.(Schubert and Minot, 2004) Findings suggesting a unilateral peripheral vestibular hypofunction occurs in approximately 10% of cases with persistent symptoms of dizziness following concussion, however a mechanism by which this occurs is not well defined(Hong et al., 2014). The head thrust test (HTT) is a clinical test that can be used to assess the response of the vestibulo-ocular reflex and has been reported to have good clinical utility when performed unpredictably and in slight craniocervical flexion(Schubert et al., 2004). Dynamic visual acuity is a test that measures the behavioural response of the vestibulo-ocular reflex and has been reported to be responsive to change with rehabilitation(Dannenbaum et al., 2009; Herdman et al., 1998).

Cervicogenic dizziness is typically described as an imbalance or sensation of disequilibrium occurring concomitantly with neck pain and stiffness or headache.(Reid et al., 2007) Cervicogenic dizziness is believed to arise from dysfunction in the upper cervical spine(Reid et al., 2017). This cervical dysfunction causes an alteration in cervical afferent input, resulting in a mismatching of input(Treleaven et al., 2016). Cervicogenic dizziness is typically a diagnosis of exclusion, once other causes of dizziness are ruled out.(Reid and Rivett, 2005) The inclusion of the joint position error (JPE), trunk relocation, smooth pursuit neck torsion, cervical torsion and cervical movement control tests as described above can contribute to a better understanding of the potential sources of cervicogenic dizziness.

The clinical presentation of dizziness may change with recovery and with increasing levels of function.(Ernst et al., 2005) For example, when individuals move slowly after injury, cervical and visual cues may be used to preplan eye movements and enable stability of gaze, thus minimizing symptoms. At faster speed of head motion, peripheral vestibular input is required to maintain a stable gaze (i.e. clear vision) with head motion (VOR). Symptoms may occur in the presence of altered VOR gain as speed of movement is increased over 2 Hz and reliance on VOR cues is necessary.(Schubert and Minot, 2004) When individuals are moving very slowly, symptoms of BPPV may be less evident as an error signal/mismatch in input does not occur. As function and speed of movement increase, symptoms of dizziness and unsteadiness may become more noticeable. These new symptoms are not secondary to new traumatic injury but rather because a mismatch in cues only occurs at faster speeds head motion. Thus, differential diagnosis and ongoing reassessment assists in understanding the source of dizziness and can identify potential treatments.

A number of different tests and measures can be used to assess the vestibular system. However, it is important to recognize that the area of vestibular assessment and rehabilitation is one that requires a great deal of additional knowledge and training that is beyond the scope of this masterclass article. Assessment of dizziness and balance disorders following concussion is important and should be a part of clinical assessment since dizziness is a common symptom following concussion and there is strong evidence for positive outcomes with vestibular rehabilitation. Thus, it is recommended that clinicians collaborate with physicians with expertise in dizziness/vestibular assessment and physiotherapists with expertise in vestibular rehabilitation to assist in the assessment and management of these disorders.

3.9. Balance

3.9.1. Postural sway/standing balance/dynamic balance

While not specific to any one disorder, both standing and dynamic balance may be altered following a concussion(Guskiewicz, 2003; Schneider, Meeuwisse, 2014b). The Balance Error Scoring System (BESS) is a clinical test with demonstrated reliability in collegiate athletes that evaluates postural sway in six conditions (Romberg, single leg stance and tandem stance on solid ground and on a foam pad) (Guskiewicz et al., 2001; Riemann et al., 1999). The Balance Examination Score (BES) is a part of the SCAT5 and is a shorted version of the BESS that includes only test positions on solid ground(Echemendia, Meeuwisse, 2017b). Changes in a variety of gait parameters may occur following concussion (Manaseer et al., 2019) and tests of dynamic balance, such as the Dynamic Gait Index and Functional Gait Assessment may be conducted(Wrisley et al., 2004). Tandem gait speed has been reported to be significantly slower in collegiate athletes acutely following concussion compared to their uninjured performance (Oldham et al., 2018). Of note, in this same sample no differences were seen in the BESS, suggesting that tandem gait may be a more sensitive measure(Oldham et al., 2018).

3.10. Dividing attention

Another area that individuals may report difficulty following concussion is when dividing attention(Parker et al., 2005). Tasks typically involve walking or standing balance with the addition of a cognitive task(Bogduk and Marsland, 1986). The currently available literature evaluating dual tasks following concussion is limited in methodological quality, however alterations in gait often occur and reduced gait velocity and increased sway have been reported when dividing attention following concussion(Fino et al., 2018; Kleiner et al., 2018). Of interest, a cohort study demonstrated improvements in times to complete a task of divided attention following concussion in youth ice hockey players (Schneider, Meeuwisse, 2018a). Thus, one should be aware of potential ceiling and floor effects as well as changes that may occur with growth and development(Schneider et al., 2017a; Wrisley et al., 2004).

3.11. Visual disorders

A variety of visual complaints may be reported following a concussion such as double vision, blurred vision, difficulty reading, words appearing to be moving on a page and eye fatigue(Capo-Aponte et al., 2012; Laukkanen et al., 2017; Master et al., 2016). These symptoms occur for a variety of reasons and a number of visual disorders have been reported following concussion, with convergence insufficiency (near point of convergence > 5 cm) and accommodation disorders reportedly the most common(Master et al., 2018; Master et al., 2016; Mucha et al., 2014; Ventura et al., 2015). Accommodation involves changing the shape of the lens to maintain focus on an object as it moves closer/farther away(Ventura et al., 2014). Vergence is the process necessary to bring the eyes together (convergence) or apart (divergence) as an object moves toward or away respectively. Difficulties with smooth pursuit, which is the ability of the eyes to follow a moving target, may also be present(Ventura et al., 2014). In addition, saccadic eye movements (rapid "jumping" type movements of the eyes to a target) may be observed during smooth pursuit. Vision and reading are complex tasks that require intact function of multiple areas of the brain as well as integrated function of multiple regions(Master et al., 2016; Ventura et al., 2014, 2015).

Individuals may have difficulty completing visual tasks or may report symptoms with testing(Mucha et al., 2014; Ventura et al., 2014). The visual examination includes evaluation of pursuit, saccades, vergence and other specific tests. The Vestibular Ocular Motor Screen (VOMS) can be used to identify tests that increase symptoms and to assess for near point of convergence (NPC)(Mucha et al., 2014). The King-Devick test is a timed test involving reading and recitation of letters in increasingly difficult situations(King et al., 2015). It is a functional task that reflects saccadic eye motion and appears sensitive to concussive injury in the early time period following concussion (Seidman et al., 2015; Ventura et al., 2015). Referral to an optometrist, neuro-optometrist or ophthalmologist with expertise in this area may be warranted for patients with visual disorders or ongoing symptoms, however current literature is limited (Ventura et al., 2014, 2015).

3.12. Exertion

There is emerging evidence that individuals with persistent symptoms following a concussion may have difficulties with exertional activities(Leddy et al., 2013a). This may be evident with symptom provocation during return to activity and intolerance to exercise(Leddy et al., 2015; Leddy et al., 2010). This has been termed physiologic post-concussion syndrome and may reflect autonomic dysfunction(Leddy et al., 2015).

Both physical and cognitive exertional testing may be performed, although as yet no valid measure of cognitive exertion exists. As symptoms alone may not adequately differentiate different subtypes of concussion (Leddy et al., 2015), assessment of the ability to exercise can be used to evaluate for exertional difficulties. Exertional testing has been shown to be feasible and safe in children and adults, but it is important to consider individual presentations and ensure safety prior to testing(Gagnon et al., 2016a; Leddy et al., 2013b). In adults, the Buffalo Concussion Treadmill Test is a commonly used test of exertion (Leddy et al., 2011). The test starts at 3.3 miles per hour with no incline on the treadmill. At 1 min, the incline grade is increased to 2.0% and at every subsequent minute the grade is increased by 1.0%. Blood pressure is taken. Heart Rate and Rate of Perceived Exertion (RPE) are measured each minute. The test is stopped with the onset of symptoms or an increase in symptoms of greater than two points from pre-test reported symptoms(Leddy et al., 2011). Another approach in children that has safely and effectively been used in clinical research is to embark on a modality of choice (either a stationary bike or treadmill) and exercise at 55%–65% of max heart rate calculated based on 220-age for as long as tolerated (up to 15 min) prior to symptoms increasing greater than 2 points(Gagnon et al., 2009, 2016b).

3.13. Cognitive difficulties

Up to 50% of collegiate athletes may report difficulty concentrating and remembering following a concussion, however these symptoms typically resolve within the initial 7–10 days(Marshall et al., 2015, McCrea et al., 2003). Cognitive symptoms can arise for a number of reasons, including pain, sleep disturbance, cognitive reserve, psychological involvement and others(Foundation, 2018). Thus, in the presence of ongoing cognitive difficulties, a neuropsychology evaluation can assist with the differential diagnosis of the underlying source of ongoing cognitive symptoms. Long lasting problems in cognitive

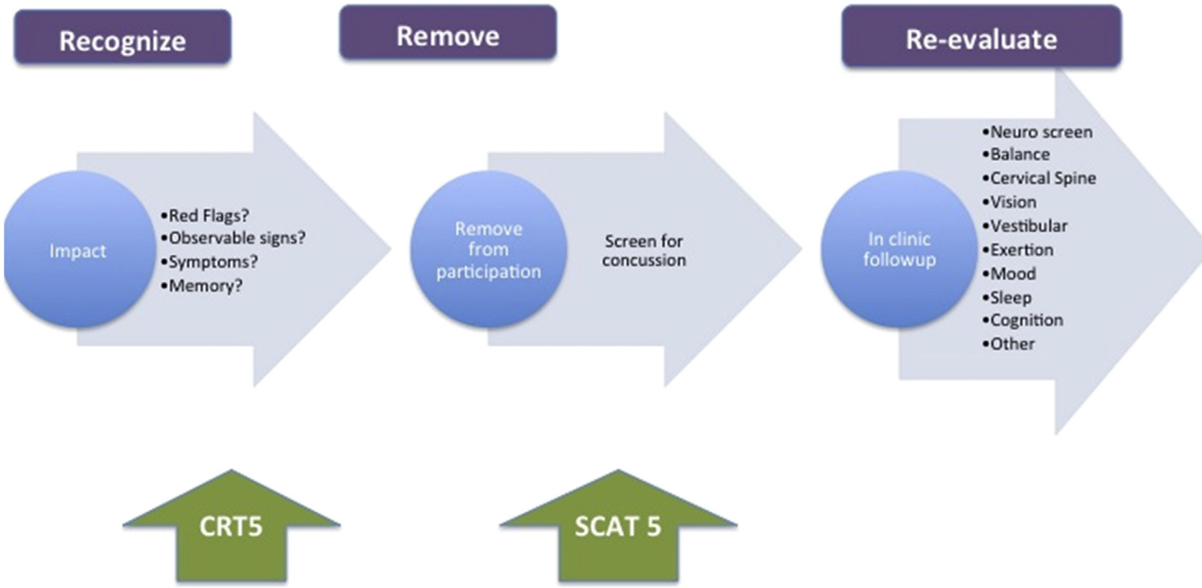

Fig. 2. Recognize, remove and re-evaluate: Steps in the initial assessment following a concussion.

functioning, as measured by standardized cognitive testing, in youth is uncommon(Brooks et al., 2013; Mannix et al., 2014). In addition, there is limited evidence to support cognitive interventions(Robinson et al., 2014). In some cases, concomitant visual or vestibular disturbances may contribute to cognitive difficulties. In the presence of ongoing descriptions of difficulties with cognitive functioning, discussion with a neuropsychologist in your area and/or referral to a neuropsychologist with expertise in concussion is warranted. Work and/or school accommodations may be required temporarily(Foundation, 2018).

3.14. Mood and mental health disorders

Feeling irritable or sad has been reported in the initial time period following a concussion by small numbers of athletes and these symptoms typically resolve within the first week following concussion (Marshall et al., 2015). Trauma can trigger mental health disorders and in cases of pre-existing diagnoses of anxiety or depression recovery may be prolonged(Iverson et al., 2017). Most current evidence suggests that psychological, behavioural and other psychiatric problems rarely remain after the acute and subacute time following mild traumatic brain injury in children and youth(Emery et al., 2016). Of interest, emotional symptoms tend to be present later on in the recovery period while physical symptoms have been reported to be present earlier on following injury(Eisenberg et al., 2014). Thus, it is important to recognize potential concurrent mental health problems and refer the patient to their physician, neuropsychologist, psychologist or psychiatrist with expertise in concussion.

3.15. Fatigue and sleep disturbance

In the general population, 34% of individuals have been reported to have sleep disturbances(Grandmer et al., 2006). Up to 20% of high school and collegiate athletes report difficulty sleeping in the early days following concussion(Marshall et al., 2015). In addition, poor sleep has been reported to be associated with poor health outcomes(Daley et al., 2009; Grandner et al., 2012). Up to 50% of individuals who suffer a mild traumatic brain injury and have ongoing symptoms report sleep disturbances(Castriotta et al., 2007; Theadom et al., 2015; Wiseman-Hakes et al., 2009). Ongoing difficulties with falling asleep, staying asleep, increased use of napping and feeling less well rested have been reported following mTBI(Ponsford et al., 2013; Sullivan et al., 2015). Poor sleep quality may be secondary to pain and if so, sleep posture should be assessed and can be modified. It has also been hypothesized that autonomic dysfunction may contribute to sleep difficulties(Leddy et al., 2017). Insomnia (as measured by the Insomnia Severity Index) has been reported to be associated with higher levels of disability and pain in adults who have suffered a mild traumatic brain injury (Mollayeva et al., 2016). Poor sleep quality (as measured by the Pittsburg Sleep Quality Index) in the initial two weeks following mTBI predicted poorer mood, cognitive ability, post-concussion symptoms and integration into the community one year post injury(Theadom et al., 2015). If ongoing sleep difficulties persist, referral to a physician with expertise in sleep management is warranted.

4. Implications

Concussion is a heterogeneous injury with a multitude of clinical presentations. Most individuals have an uncomplicated recovery, but some have ongoing symptoms that are amenable to treatment. In the acute setting, screening for red flags and more serious pathology is imperative. The SCAT5 (or Child SCAT5) can be used as multifaceted screening tools but should not replace the clinical examination. Follow-up for medical assessment and an initial period of both cognitive and physical rest for the initial 24–48 h is recommended. Additional screening tools that assess vestibular and oculomotor signs and symptoms can be considered in the subacute time period following concussion(McDevitt et al., 2016; Mucha et al., 2014) (See Fig. 2). After an initial 24–48 h of cognitive and physical rest, an active return to activities is recommended in a sequential fashion (see Masterclass Part II).

If symptoms are not resolved in the 7–10 days following concussion, a more detailed multifaceted assessment of the variety of domains that may be affected by concussion will facilitate management and/or appropriate referrals(Leddy et al., 2015). Assessment should include symptom reports, a neurological examination (including a cranial nerve scan, cerebellar scan, manual muscle testing, deep tendon reflexes, sensation), cervical spine motion and exam, sensorimotor, neuromotor control, oculomotor function, vestibular, standing balance, dynamic balance, exertion testing and a detailed headache assessment (See Fig. 4). In addition, screening for co-occurring disorders such as depression, anxiety, substance abuse and others should be included in the assessment and can help to inform management(Matuszak et al., 2016).

An interdisciplinary team approach is recommended following concussion. In some cases, targeted areas for rehabilitation will be identified that can be managed by specific health care professionals

Fig. 3. Common symptoms following concussion.

Fig. 5. Dix-Hallpike test position: (a) 30° extension and (b) 45° rotation.

with expertise in a given area. In other cases, where multiple clinical findings in different areas are identified, a full team of health care professionals and/or program may be needed. The physiotherapist is an integral member of the interdisciplinary team. However, varying skill-sets and areas of clinical competency should be recognized (i.e. vestibular rehabilitation vs manual therapy vs sport physiotherapy). Ongoing communication and collaboration with an interdisciplinary group of healthcare professionals is important in the care of individuals who have suffered a concussion as many different systems can be affected. Development of a team of providers with diverse expertise will facilitate optimized care of this most complex condition. Part II of this Masterclass outlines the evidence and rationale for treatment following concussion.

Conflicts of interest

None Declared.

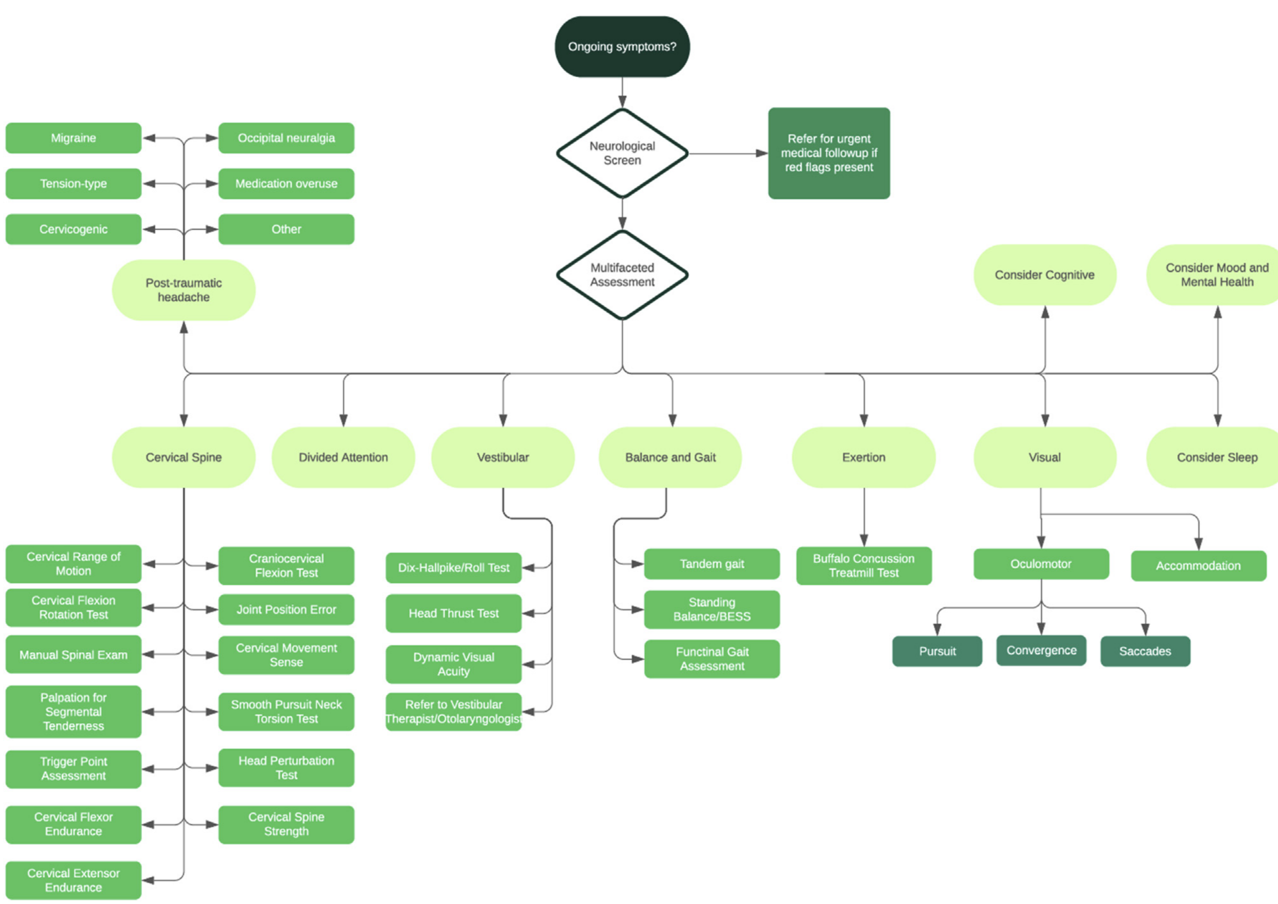

Fig. 4. Differential diagnosis of ongoing symptoms following concussion.

Ethical approval

Not applicable.

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Competing Interests

There are no competing interests to declare.

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