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REVIEW ARTICLE

# Assessment, Management and Knowledge of Sport-Related Concussion: Systematic Review

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**Abstract**
*Background* Sport-related concussions are a subset of mild traumatic brain injuries and are a concern for many sporting activities worldwide.
*Objective* To review and update the literature in regard to the history, pathophysiology, recognition, assessment, management and knowledge of concussion.
*Methods* Searches of electronic literature databases were performed to identify studies published up until April 2013.
*Results* 292 publications focussing on concussion met the inclusion criteria, and so they were quality rated and reviewed.
*Conclusion* Concussion is hard to recognize and diagnose. Initial sideline assessment via the Sports Concussion Assessment Tool 3 (SCAT3), Child-SCAT3 or King-Devick test should be undertaken to identify athletes with concussion as part of a continuum of assessment modalities and athlete management. Sports medicine practitioners should be cognisant of the definition, extent and nature of concussion, and should work with coaches, athletes and trainers to identify and manage concussions. The most common reason for variations in management of concussion is lack of awareness of—and confusion about—the many available published guidelines for concussion. Future research should focus on better systems and tools for recognition, assessment and management of concussion. Sport participants' knowledge of concussion should be evaluated more rigorously, with interventions for sports where there is little knowledge of recognition, assessment and appropriate management of concussion.

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## 1 Introduction

Known as the 'silent injury' [1] and often trivialized by the media and sporting circles as a 'knock to the head' [2], sport-related concussions (hereafter called 'concussion') are a subset of mild traumatic brain injuries (mTBIs) [3] and have become an increasingly serious concern for all sporting activities worldwide [4–6]. The term 'concussion' is a historical term, as it represents low-velocity injuries that cause 'brain shaking' resulting in clinical symptoms, and it is often used interchangeably with 'mTBI' in the sporting context and in the published literature [3]. In the USA, it is estimated that 1.6–3.8 million sport-related concussions occur annually [7], accounting for 5–9 % of all sport-related injuries [8, 9]. Amongst 15- to 24-years-olds, concussions are second to road trauma as the most common causes of traumatic brain injury (TBI) [10]. Guskiewicz [11] reported that of the 5.1 % of 17,549 collegiate and high school football players who sustained at least one concussion during matches over a single season, 14.7 % sustained a subsequent concussion, with 30 % of players returning to the same match [12]. Despite the frequency of concussions, they are often underreported [12]. In the past 30 years, clinicians have gone from anecdotal strategies to an international consensus-based approach for

(1) identification and management of concussions; (2) evidence-based practice; and (3) a new focus on education and injury prevention [13].

Concussions are known to affect reaction time [14], memory [14–16], balance [17] and planning skills [16]. Previous concussions may place the athlete at higher risk (1.4–11.1) of sustaining a subsequent concussion [11, 18, 19]. Additionally, 1–29 % of concussions occurring in a single season are reported as subsequent concussions [11, 20]. Repeat concussions may result in long-term outcomes, which include depression [21], mild cognitive impairment [22], prolonged recovery from subsequent concussions [14, 19], electrophysiological changes [5] and chronic traumatic encephalopathy (CTE) [23], but to date there have been no direct causal relationships identified to support these relationships [24]. Despite these findings, the range and extent of long-term effects from repeat identified concussions remain unclear [25].

Although there is increased understanding about the consequences of returning the concussed athlete too soon and the effects of repeated concussions over time, it is important to remember that every concussion is unique and should be managed individually [26, 27]. With this in mind, the aim of this article is to review and update the literature on concussion in relation to the history, pathophysiology, recognition, assessment, management and knowledge of concussion.

## 2 Methods

Guidelines for the reporting of observational studies (MOOSE: Meta-analysis Of Observational Studies in Epidemiology) [28], systematic reviews (PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [29] and observational studies (STROBE: STrengthening the Reporting of OBservational studies in Epidemiology) [30], and for appraising research (AGREEII: Appraisal of Guidelines for REsearch & Evaluation v.II) [31], were followed for the different studies included in the review. These checklists contain specifications for conduct and review of the various studies that were included.

### 2.1 Search Strategy for Identification of Publications

A total of 38,333 studies published from 1948 to April 2013 identified through databases were screened for eligibility (see Fig. 1). The keywords that were utilized for the search of relevant research studies included combinations of 'sport*-related', 'sport*', 'concussion', 'mild traumatic brain injury', 'mTBI', 'epidemiology', 'history', 'pathophysiology', 'return-to-play', 'RTP', 'management', 'gender', 'academic', 'history', 'post-concussion', 'assessment', 'management' and 'knowledge'. Additional relevant studies were identified using the bibliographies of those articles found in the literature searches.

To establish some control over the heterogeneity of the different studies [28], inclusion criteria were established. Any published study or book that did not meet the inclusion criteria was excluded from the study. A total of 286 publications were identified that reported on concussion and met the following inclusion criteria:

(i) The study was published in a peer reviewed journal or book; and
(ii) The study specifically addressed areas relating to concussion review (i.e. history, pathophysiology, definitions, symptom assessment and management, risk factors for and modifiers of linear and/or rotational acceleration–deceleration forces, and knowledge and understanding of player, team management, medical personnel, return to play and other activities).

Reviewed studies were excluded from this review if it was identified that the publication:

(i) Was unavailable in English; or
(ii) Did not provide additional information for any of the identified sections and subsections of this review; or
(iii) Had not been referred to by other included publications.

### 2.2 Assessment of Publication Quality

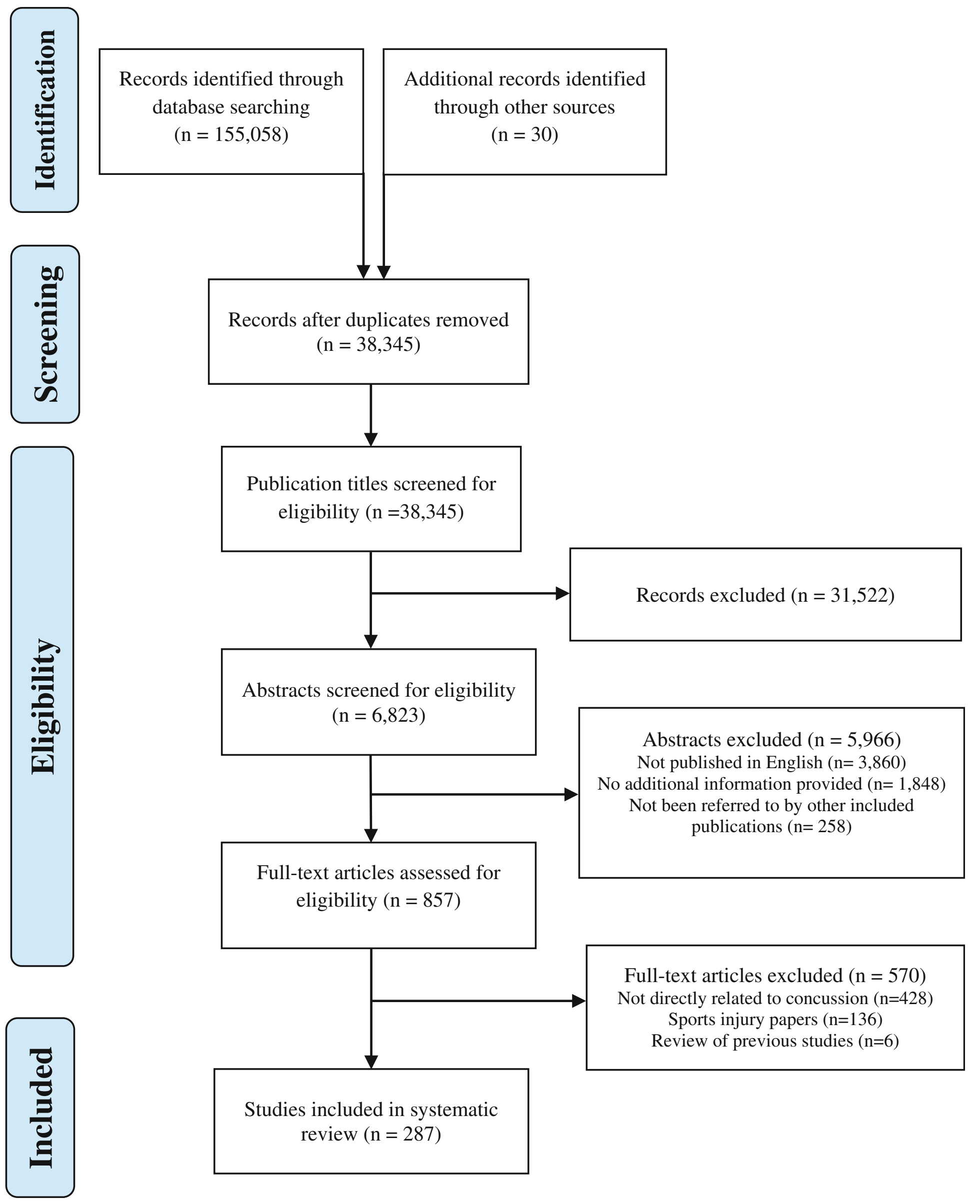
All studies that met the inclusion criteria were assessed for quality on the basis of previously published checklists [28–31]. Heterogeneity of the studies included in the literature review was expected, as there might be differences in the study design, population and outcomes [28]. For this review, quality was described as confidence that the study design, conduct and analysis minimized bias in estimation of the effect of the risk factor on the outcome measures [30].

The quality scores by checklist were:

(i) MOOSE [28]: median score 5/6; range 2–6 [4, 5, 8–11, 14–23, 25, 33–148];
(ii) PRISMA [29]: median score 23/27; range 17–24 [149–177];
(iii) STROBE [30]: median score 10/14; range 4–12 [178–184]; and
(iv) AGREEII [31]: median score 124/161; range 51–136 [3, 13, 24, 152, 164, 168, 185–203].

The remaining included studies [1, 6, 7, 12, 26, 27, 157, 174, 177, 182, 204–274] recorded a median score of 5/27

**Fig. 1** Flow of identification, screening, eligibility and inclusion for the literature review of sport-related concussions




(range 2–6) on PRISMA but provided additional information for the review and were included despite their low PRISMA ratings.

## 3 Results and Discussion

### 3.1 Historical Perspectives

Descriptions and recordings on head injuries or 'commotio cerebri' date back more than 3,000 years [231, 253, 269]. Writing from Greek medicine as early as 1700 BC through to Roman, Byzantine, Arabic and French medical writing include descriptions of the understanding and management of head injuries [253, 255]. The term 'concussion' was not used until the seventeenth century, when Venetian physician Petri de Marchetti (1665) described the condition as being transient, with a short duration of "*alienation of the mind, with privation of sense and motion*" [253, 255]. In the nineteenth century, Bell introduced a new concept to the entity of concussion, describing the use of clinical signs to distinguish between different types of brain injury (concussion, compression and inflammation) [253].

As the understanding of the pathology of concussion developed, new physiological theories [253, 255, 266, 269] and models [244] were formulated and advocated, emphasizing a functional rather than a structural process of concussion [253, 255, 266, 269]. Despite these theories, concussion remains a mystifying subject in sports medicine [269]. Theories have provided valuable knowledge towards modern-day understanding of concussion, providing a glimpse into the pathophysiology that the brain undergoes when a concussion occurs [253]. Although some of these theories have been rejected, others continue to be used in developing an understanding of concussion [253]. Future research on the understanding of concussion is warranted.

### 3.2 Definitions

A concussion is hard to recognize and diagnose [193, 249]. Use of terms associated with injuries to the head, such as 'dings' or having one's 'bell rung', are commonplace and serve only to diminish the perception of injury severity and to perpetuate the notion that concussion is something people can play through [249]. By definition, concussion and mTBI overlap, as both terms represent the less severe end of the TBI spectrum [3, 160, 193, 237, 252]. Both terms identify that there is acute neurological dysfunction in the absence of significant microstructural damage [160, 229]. This generally recovers over time, with most people typically having resolution of symptoms within 7–10 days [3]. The full spectrum of TBIs (mild, moderate and severe) would see concussion below the mild classification in a 'minimal' range as TBI reflecting no neurosurgical significance of a pathological injury [168]. In Europe, the term 'commotio cerebri' is often used in place of the term 'concussion' to represent a low-velocity injury that results in 'brain shaking' resulting in clinical symptoms not necessary related to pathological injury [168]. The term 'concussion' is more frequently utilized in sports and clinical settings [237]. It is the preferred terminology, as it is more easily understood by most patients, is easier to communicate regarding the prognosis and is less likely to have an adverse psychological effect on the person when they learn about their injury [237].

Ever since concussion was described in the medical literature, there have been numerous attempts to establish a working definition [9, 13, 186, 187, 189, 194, 197, 203, 212, 239, 240, 264]. Consequently, the definition of concussion has changed over time [253], as universal agreement on a single definition has been difficult to reach [213, 243]. In 2001 at the First International Concussion In Sport (CIS) Conference, the Concussion In Sport Group (CISG) considered a more inclusive and elaborative definition of concussion [187]. This definition incorporated common concepts from different definitions of concussion that had been previously published, and did not consider loss of consciousness as an essential defining characteristic [27]. Despite this, loss of consciousness may, or may not, be present as a feature of concussion, as symptoms are transient and global in nature [27]. The subtle nature of the symptoms and pathology makes the diagnosis of concussion a challenge [27].

Since the publication of the first CIS consensus statement and definition of concussion, variations of the definition have been produced [11, 152, 174, 177, 192, 193, 200, 202, 273, 274]; until a universal definition is used for identification and reporting of concussion, the true epidemiological incidence of concussion will not be identified.

### 3.3 Concussion Pathophysiology

When direct or indirect linear and/or rotational forces are applied to the brain [26, 187, 194, 216], the underlying neural elements are exposed to a shearing strain [93, 226, 245, 261]. Following this shearing strain, there is an alteration to normal brain functioning, termed 'neurometabolic cascade'. This places the brain cells in a vulnerable state as a result of ionic, metabolic and pathophysiological events accompanied by microscopic axonal injury [26, 82, 121, 142, 204, 225, 226, 236, 241, 267, 269]. These disruptions require energy to re-establish homeostasis, but this occurs in the presence of ongoing mitochondrial dysfunction and decreased cerebral blood flow, resulting in an imbalance of energy supply and demand [121, 204]. This may occur anywhere from minutes to days following the event [216, 269].

The pathophysiological effects of concussion can be seen within 24 h of the event, lasting up to several weeks post-injury [26, 226, 241]. Experimental evidence indicates that the concussed brain may be less responsive to physiological neural activation [121, 204]. A second injury to the brain in this vulnerable period may result in a worsening of cellular metabolic changes associated with more significant cognitive deficits [121, 267]. These perturbations are more pronounced in youth, raising concerns that the immature brain may be more susceptible to repeat concussions before complete recovery occurs [267]. Excessive cognitive or physical activity before complete recovery may result in prolonged dysfunction [204, 267]. As a result of the increased metabolic dysfunction, the brain may have increased vulnerability to other consequences, such as second-impact and post-concussion syndromes if a subsequent insult (even minor) were to occur [241, 267], although this has not been well established [166].

### 3.4 Subconcussive Pathophysiology

A subconcussive injury is a theoretically very mild, biomechanically induced brain injury. These may occur in the absence of overt clinical symptoms of concussion [160], loss of match or training time, or concussion-related symptoms that linger for a prolonged period of time [40, 43, 216]. Non-concussive impacts that occur during sport participation may result in sub-clinical decline [37, 43, 208, 216]. Some athletes without a clinically diagnosed concussion or clinically observed symptoms of concussion have had neurocognitive and neurophysiological impairments that may be accumulative [136].

Similar to the pathophysiology of concussion, subconcussive incidents have also been shown to induce a neuro-inflammatory response in rat studies [128]. This neuro-inflammatory response can occur in the absence of any significant axonal injury or of emotional, cognitive or sensorimotor disturbances [216]. The neuro-inflammatory response seen in repeated subconcussive head traumas may have cumulative effects [117, 127, 216]. This response has been linked to neurodegenerative disorders such as CTE [105, 128, 133, 207], post-concussion syndrome, post-traumatic stress disorder, mild cognitive impairment and dementia pugilistica [216], but no direct causation between concussions and these disorders has been demonstrated [3].

### 3.5 Symptom Assessment

Difficult to diagnose [168], the symptoms of a concussion can vary in nature, and the measurement of these depends upon the self-reporting of the athlete. Traditionally, loss-of-consciousness (LOC) was considered to be the hallmark of concussion [159], but this has been revised, with only 8–9 % of all concussions [11, 19] resulting in LOC. More common symptoms of concussive events are amnesia (13–24 %) [19, 62, 118] and confusion/disorientation, which may present in 45–90 % of all athletes with a concussion [62, 98]. Other symptoms that may present following a concussive event are changes to the athlete's physical, cognitive affective (or emotional) and sleep domains [114].

Physical symptoms that may manifest are headache, dizziness, nausea, vomiting, sensitivity to light and/or noise, and drowsiness [114]. Reported cognitive changes are that athletes feel they are in a 'fog', have difficulty remembering and feel slowed down [114]. Several cognitive domains are negatively affected following a concussive incident. This is evidenced by the deficits identified through neuropsychological testing, with changes recorded in attention/concentration [59, 72], speed of information processing [98], verbal learning [59], visuo-spatial memory [96], working memory [59], verbal memory [59] and reaction time [146]. Affective symptoms that may present are irritability, sadness and anxiety, while changes in the athlete's sleep domain may manifest as sleeping less or more than usual, trouble falling asleep and drowsiness [114]. To complicate the assessment of concussion further, some of these deficits may not be present for every athlete, thus making this an individualized injury.

Concussion symptoms typically resolve in 80–90 % of all sport participants by 7–10 days post-injury [65, 94, 99, 100, 103, 107, 151, 213]. Concussion symptoms, by their very nature, are subjective and depend upon awareness [104], honesty and willingness of the athlete to accurately provide the information [104, 149]. Resolution of concussion symptoms may not always indicate complete cognitive recovery, as persistent deficits may still be present [103, 248], and the clinical importance of these changes in the absence of symptoms is unknown [193]. Throughout the development of knowledge of concussion, there have been a number of self-reported symptom scales [13] and checklists [47] published in an endeavour to assist the clinician to objectively document the symptoms of concussion and any changes that occur [149] (see Table 1).

Following the 2004 Second CIS Conference, the Sports Concussion Assessment Tool (SCAT) was published as part of the summary and agreement statement of those who attended the conference [194]. SCAT was based on expert consensus of the best measures to assess concussion that were currently available [194]. The Third International CIS Conference in Zurich [13] resulted in SCAT being amended, and SCAT2 and PocketSCAT2 were produced. Embedding the Sideline Assessment of Concussion (SAC) and a modified Balance Error Scoring System (BESS), SCAT2 uses a score range of 0–100 points, with lower scores indicating poorer performance. SCAT2 was designed for serial use after a concussion and included a score card designed to enable tracking of the concussed athlete's performance. SCAT2 is a longer sideline concussion tool designed for medical practitioners to enable more detailed assessment of concussion, while PocketSCAT2 was designed for sideline recognition of screening for concussion for the non-medically trained [3]. Although SCAT2 is an improvement over the original SCAT, it requires additional time to complete on the sideline, making this more of a training room assessment tool [157].

More recently, the Fourth CIS Conference reviewed SCAT2, and SCAT3 was produced, along with Child-SCAT3 and the Concussion Recognition Tool (CRT) [3]. The components of SCAT3 have been shown to be reliable and valid through several studies and have resulted in psychometric properties for reliability (0.54–0.94), sensitivity (0.34–0.94) and specificity (0.76–1.0) [191]. As a result of the review, SCAT3 is designed for participants over 12 years of age, while Child-SCAT3 is for sport participants aged between 5 and 12 years, with modification of the Maddocks questions [3]. CRT is an updated version of PocketSCAT2 but does not have a child version for the modified Maddocks questions asked in Child-SCAT3.

### 3.6 Neuropsychological Assessment

Introduced in the 1980s, neuropsychological assessment has become widespread with the availability of computers

**Table 1** Summary of the concussion symptom scales/checklists published from 1995 onwards [149]

| Year | Scale name | Grading scale | No. of items |
|---|---|---|---|
| 1980s; 1990s | Pittsburgh Steelers Post-Concussion Scale[a] | 7-point Likert Scale | 17 |
| 1998 | Post-Concussion Scale (PCS)[b] | 7-point Likert Scale | 20, 21, 18 |
| 1999 | Post-Concussion Symptom Assessment Questionnaire (PCSQ)[a] | Yes/no with 10 cm VAS | 10 |
| 2000 | Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Post-Concussion Symptom Scale (ImPACT-PCSS)[b,c] | 7-point Likert Scale | 22, 21, 19 |
| 2001 | Concussion Resolution Index–Post Concussion Questionnaire (CRI)[a,c] | 4-point Likert Scale | 15 |
| 2001 | Vienna Post-Concussion Symptom Scale[b] | 7-point Likert Scale | 20 |
| 2001 | McGill Abbreviated Concussion Evaluation–Post Concussion Symptom Scale[b] | 7-point Likert Scale | 20 |
| 2003 | Graded Symptom Checklist/Scale (GSC/GSS)[b] | 7-point Likert Scale | 20, 27, 18, 17 |
| 2003 | Head Injury Scale (HIS)[b] | 7-point Likert Scale | 16, 9 |
| 2003 | CogState-Sport Symptom Checklist[a,b] | 7-point Likert Scale | 25, 21, 14 |
| 2004 | Signs and Symptoms Checklist (SSC)[a] | Yes/no | 34 |
| 2004 | Sport Concussion Assessment Tool–Post Concussion Symptom Scale (SCAT-PCSS)[a] | 7-point Likert Scale | 25 |
| 2009 | Concussion Symptom Inventory (CSI)[a] | 7-point Likert Scale | 12 |

*VAS* Visual Analogue Scale

[a] Core scales

[b] Variants of the Pittsburgh Steelers Post-Concussion Scale

[c] Computer-based scale

enabling computer-based testing, and it is seen as a 'cornerstone' in the management of concussion [3, 154, 162, 193, 194, 275]. Designed to identify occult cognitive impairment post-injury, neuropsychological testing has been able to identify neurocognitive deficits within 2–48 h post-injury [155] and can show cognitive deficits despite athletes reporting they are asymptomatic [13, 147, 158, 162, 194]. Neuropsychology is also a useful tool for documenting athletes' recovery from a concussion by measuring several domains of cognitive function [3, 13, 158, 162, 194]. The areas measured vary by test type and focus on cognitive processing speed, reaction time and memory.

Neuropsychological tests can be divided into two types on the basis of their method of administration, either pencil-and-paper or computer based. Both forms of neuropsychological testing have some variability in regard to the measurement of domains and performance in areas such as the Reliable Change Index, sensitivity and validity [175, 179, 193]. Pencil-and-paper tests are administered and interpreted by a neuropsychologist [154, 194], are often more comprehensive and may test additional domains, enabling assessment for other conditions that may masquerade as a concussion or post-concussion syndrome [175]. However, these tests often require more time to administer, can be labour intensive and are more expensive than computerized neuropsychological testing [156, 158, 179].

Computerized neuropsychological tests have become more common in the athletic setting, as they can be administered concurrently to groups of athletes, have more precise measurements of reaction time, provide instant information to the provider, take less time to administer, are less expensive and can store large amounts of data [155, 156, 158, 162, 193, 194]. These tests have been adopted as a core component of many concussion management programmes [276]. Computerized neuropsychological tests have been validated against paper-and-pencil tests [277, 278] and post-concussion symptoms scores [279, 280] by different groups [158, 277–280], with overall specificity and sensitivity of between 80 and 90 % [279]. The advantages of using computerized neuropsychological tests include ease of administration; ease of data retrieval; automated data collection, storage, analysis and interpretation; high sensitivity to subtle cognitive effects; measurement of multiple domains of performance and variability; measurement of the extent of cognitive malfunction during the recovery process; and ability to control stimuli and stimuli characteristics [27, 281]. However, there are several drawbacks to computerized neuropsychological testing when compared with pencil-and-paper neuropsychological tests. Computerized neuropsychological tests (1) do not fully assess memory functioning—they only examine recognition memory; (2) minimize the interaction between the neuropsychologist and the athlete, reducing observation of performance; (3) limit the assessment of the effort and motivation of the athlete, because of group administration; (4) limit the ability to examine the injured athlete's problem-solving and information-learning processes [155]; and (5) have varying test–retest reliability [276, 282, 283]. Other possible limitations to the use of computerized neuropsychological testing are that computer programs can introduce complex instrumentation errors due to timing accuracy across different computer platforms, the computer's processor speed, the type of mouse used and if the test is administered across the internet [155]. Despite the drawbacks, computerized neuropsychological tests are utilized through a variety of computer-based batteries such as Immediate Postconcussion Assessment and Cognitive Testing (ImPACT Inc., Pittsburgh, PA), CogSport (CogState Ltd, Melbourne, Australia), Automated Neuropsychological Assessment Metrics (ANAM developed by the US Department of Defense) and Headminder (ImPACT Applications, Inc; Axon Sports, LLC) [155, 156].

Neuropsychological tests for pre-adolescent sport participants have been reported [156, 284, 285]. Although the key assessment domains in this group of sport participants are generally similar to those in adolescents and adults, important differences must be accounted for, such as pre-adolescent cognitive, physical and emotional differences, as well as the capacity of the pre-adolescent to be aware of and to report their symptoms [156, 286]. The computerized neuropsychological tests utilized in pre-adolescent sport participants have shown promising results, but there is a lack of evidence to draw any firm conclusion in relation to the clinical utility of neuropsychology in this group [156, 160]. There is a paucity of evidence of neuropsychological tests having been applied to pre-adolescents who have sustained a sport-related concussion [156].

Although neuropsychological testing has moderate sensitivity for the detection of post-concussive cognitive deficiencies [158, 193], it has not been validated as a diagnostic tool [193]. As such, neuropsychological testing has been promoted as a monitoring tool for the recovery of the concussed athlete [13]. It has been recommended that neuropsychology should be utilized not as the sole basis of management of concussions but as an aid to the clinical decision-making process in conjunction with a range of assessments of different clinical domains and investigations [3, 155, 156, 193]. Healthcare professionals may often administer neuropsychological tests, but the interpretation of these tests can be complex. It is therefore recommended that interpretation of neuropsychological test results is best undertaken by a trained neuropsychologist [3, 156, 281]. The use of baseline, or pre-competition, neuropsychological assessments may be of benefit to assist in post-concussion evaluations, and it is thought that these may increase the diagnostic accuracy when compared with post-injury scores [156]. Mandatory baseline neuropsychological testing is not considered a requirement for the assessment process, nor is there sufficient evidence to recommend this, but baseline neuropsychological tests can add an educative opportunity to discuss the significance of the injury [3]. For a more in-depth review of the advances in neuropsychological assessment of sport-related concussion, readers are directed to Echemendia et al. [156].

### 3.7 On-Field or Sideline Assessment of Concussion

Typically, sideline assessment of concussion involves brief tests that can be conducted on the sideline of a field or court [183]. The purpose of these tests is to rule out a more serious injury and to commence an individualized concussion management process based on the results of the assessment of cognitive and balance deficits or impairments [157]. These sideline tests are designed to evaluate attention and memory (Maddocks test) [250], cognition (SAC) [182] and postural control (BESS) [56]. The use of sideline tools for assessment of concussion is seen as an abbreviated sideline assessment and is not designed to take the place of more comprehensive evaluation or neuropsychological testing [171].

Undertaking a sideline or on-field assessment of concussion has been a challenging responsibility of the healthcare provider [199, 206]. This is often a rapid assessment process in the midst of competition with time constraints. Without qualified healthcare providers available to make the assessment, often players are returned to the field of participation [190]. Even with qualified health care professionals available at the sideline, they may not be aware of the latest guidelines or assessment tools to assist in the evaluation of a concussed sport participant [217]. The assessment can be difficult to undertake if classic indicators (e.g. loss of consciousness, amnesia, focal neurological abnormalities) are not manifested and only subtle signs and symptoms are present, raising the suspicion that 'something's off' and that a concussion may have occurred [182]. Some sports are now introducing a 'concussion bin' where players can be removed from match participation by substitution. The suspected concussed player can be assessed, in a specified time frame, enabling testing to be completed to identify, or rule out, the occurrence of a concussive injury [199]. It has been recommended that in conducting a sideline assessment for concussion, a minimum rest period of 15 minutes should occur before the full test is completed, to avoid the influence of exertion or fatigue on the assessment

[191]. Further research is required in order to enable validation that these tests are able to identify concussions even with subtle changes occurring.

There have been robust public education outreach efforts undertaken to assist non-healthcare-trained individuals to recognize and manage individuals with signs of concussion while they are participating in sporting activities [199]. These efforts have included freely available online information and encouragement for referral of the concussed athlete to a qualified healthcare provider for confirmation and management of the concussion [199]. This has been undertaken to the extent that legislative efforts have been implemented to improve safety measures for younger athletes and to standardize of the roles and responsibilities of the athletes, parents/guardians, coaches and healthcare providers [199]. As the CISG update [3] has only recently been published, there are currently no published studies to see if this information has aided in the promotion of concussion awareness. Further research is warranted to identify a wide range of sports team administration knowledge on the recognition and management of athletes with concussion.

Until the recent publication of Child-SCAT3 [3], there were no specifically developed sideline concussion assessment tools for children [153]. Symptom scales need to be available that include the language that is understood by this age group and symptoms that are familiar to them [153]. The use of SAC has been evaluated for use in children, but no symptom scales have been evaluated for use on the sideline with children [153].

Originally developed as a reading tool to assess the relationship between poor oculomotor functions and learning disabilities, the King-Devick test uses a series of charts of numbers that progressively become more difficult to read in a flowing manner [66, 67]. The use of oculomotor function requires integration of multiple sensory inputs, motor efforts [246] and cognitive processes such as target selection, sustenance of attention, spatio-temporal memory and expectation [205]. More recently, poor oculomotor function has been determined as one of the most robust discriminators for identification of an mTBI [180].

Recently, the King-Devick test has been used successfully to identify concussion in mixed martial arts; boxing [66]; university sports such as American football, soccer and basketball [67]; ice hockey [68]; rugby league [86]; and rugby union [87]. Designed as a saccadic rapid number reading tool, the King-Devick test [66–68, 86, 87] is able to be completed on the sideline in less than a minute and has been correlated with the Military Acute Concussion Evaluation (MACE) ($r_s = -0.54$; $p = 0.07$) [49] and the Standardized Assessment of Concussion (SAC) ($r_s = 0.25$; $p = 0.01$) [68]. Although the King-Devick test has been able to identify unwitnessed concussive events on-field [86, 87] and when there have been no changes on the SCAT2 SAC components [68], there have been no longitudinal studies to assess the reliability, validity or generalizability of the King-Devick test, nor has it been tested across various age groups [67].

### 3.8 Grading Scales

Historically, the decision on the management of concussion has been based upon 'grading scales' of the severity of concussion [163]. These were used to differentiate the strategies to enable return of the athlete to the sporting environment. Three commonly utilized scales were the American Academy of Neurology (AAN) [185], the Cantu [210], and the Colorado Medical Society [188] scales (see Table 2). The grade (or severity) of the concussion was based on the symptoms that were present and whether they abated in a specified time frame, and guided the return-to-play (RTP) of the athlete. For example, in the AAN scale [185] a grade 1, or mild, first concussion resulted in a player being removed from the activity but being able to return on the same day if they reported no symptoms 15 min after they were removed. Should they incur a second concussion on the same day, then they were required to be removed from the activity but could return a week later. When compared with the Cantu scale [210], there was no time limit for a first-time grade 1 being returned to play, but they were required to sit out 2 weeks if they incurred another concussion. The Colorado scale differed slightly, with a grade 1 concussion to be returned in 20 min if symptom free, and if they recorded another concussive injury, they could go back to the activity a week later. The variability and multitude of the grading scales highlighted the lack of consensus on the grading of concussion, which resulted from the absence of evidence-based data [163].

At least 16 different head injury grading scales have been published [163]. These were based on clinical experience and anecdotal evidence rather than research-based evidence [163, 238, 287], with most scales being biased towards identification of the most severe injury [163]. As no perfect scale exists that is both scientifically validated and practical [163, 238, 252], no scale was endorsed by the CISG at the First CIS Conference [187]. It was recommended that a clinical construct should be utilized on the basis of assessment of injury recovery [187]. Following the Second CIS Conference [194], it was recommended that concussions be categorized as either simple (resolution of symptoms without complication over 7–10 days) or complex (persistent symptoms, specific sequelae or prolonged cognitive impairment following the injury). Although this was seen as an advancement in the classification of concussion injury severity, the use of this terminology was limited, as it was not able to predict injury severity at the

**Table 2** Return-to-play (RTP) guidelines

| RTP guideline | Severity | 1st concussion | 2nd concussion | 3rd concussion |
|---|---|---|---|---|
| Colorado Medical Society [188] | | | | |
| | Grade 1 (mild) | RTP if no sx 20 min | Terminate game, RTP if no sx 1 week | Terminate season, RTP 3 months if no sx |
| | Grade 2 (moderate) | Terminate game, RTP if asx 1 week | Consider terminating season but consider RTP if no sx 1 month | Terminate season, RTP next season if no sx |
| | Grade 3 (severe) | Terminate game, transport to ER, RTP 1 month after 2 weeks with no sx. OK to condition after 1 asx week | Terminate season, RTP next season if no sx | Terminate season, highly recommend avoidance of contact/collision sports |
| Cantu [210] | | | | |
| | Grade 1 (mild) | RTP if no sx | RTP in 2 weeks if no sx 1 week | Terminate season, RTP next season if no sx |
| | Grade 2 (moderate) | RTP if no sx 1 week | 1 month restriction, RTP if no sx 1 week, consider terminating season | Terminate season, may RTP next year if no sx |
| | Grade 3 (severe) | 1 month restriction, RTP if no sx 1 week | Terminate season, RTP next year if no sx | |
| American Academy of Neurology [185] | | | | |
| | Grade 1 (mild) | Removal from competition, examination at 5 min, RTP same day if post-concussive sx resolve within 15 min | Incurring a 2nd concussion on the same day, RTP when no sx 1 week | |
| | Grade 2 (moderate) | Removal from competition, if sx worsen or persist >1 week, then extensive diagnostic testing. RTP when no sx 1 week | Incurring a grade 2 concussion subsequent to a grade 1 concussion on the same day, then restrict from competition until no sx 2 weeks | |
| | Grade 3 (severe) | Brief: RTP when asx 1 week<br>Prolonged: RTP when asx 2 weeks<br>Prolonged LOC or abnormal neurological signs on initial examination: transport to ER. No sports activity until asx 1 month. Any athlete with abnormality (swelling, contusion or other intracranial pathology) on CT or MRI: no RTP that season and strongly discourage from future participation in contact sports | | |

In all RTP guidelines, 'asymptomatic' means no post-concussion symptoms, including retrograde or anterograde amnesia, at rest or with exertion [209]

*asx* asymptomatic, *CT* computed tomography, *ER* emergency room, *LOC* loss of consciousness, *MRI* magnetic resonance imaging, *sx* symptoms

time of the concussive injury occurring, and it did not fully define the entities of concussion [13]. Consequently, at the Third CISG Conference [13], the terminology of 'simple' and 'complex' was rejected. Consequently, there are no recently published scientifically validated grading scales available for use with concussion. Despite this, some studies [288] and guidelines [289] still utilize the grading scales for concussion assessment, further highlighting that the CIS statement is not universally accepted.

### 3.9 Risk Factors/Modifiers of Concussion

Several risk factors and modifiers, including age and gender, may influence the risk of a sustaining a concussion or of having a protracted period of concussion resolution, although the Fourth CIS Conference found no universal agreement that female gender was a modifying factor [3]. Females sustain more concussions than males, have a greater number and severity of concussion symptoms and require a longer duration to recover [8, 34, 47, 52, 53, 55, 78, 94, 100, 125, 140, 148, 215, 221, 242, 270]. Although younger sport participants may have a more prolonged recovery period and are more susceptible to concussions accompanied by a catastrophic injury [64, 110, 129, 184, 226, 267], there is a paucity of studies reporting on recovery patterns for participants under the age of 15 years. The risk for younger sports participants is hypothesized to be related to physiological differences between younger and more developed brains [131, 240].

Genetics, mood disorders, migraines, learning disabilities and attention disorders are associated with modifiers for concussions and prolonged recovery [164]. Although some studies have suggested that there may be an association between concussion and genetic polymorphisms (i.e. apolipoprotein e4 [APOE e4] and APOE G-219T) [90, 138, 139], these studies have been limited by methodological weaknesses and did not support definitive conclusions [138, 139]. A mood disorder history, either pre-existing or resulting from a concussive injury, may compound the diagnosis and management of concussion [89, 124]. However, there is no evidence that pre-existence of a mood disorder predisposes the sport participant to a concussion [193]. It is difficult to evaluate an individual for symptoms of a concussion without being able to differentiate between symptoms that preceded the concussion from those caused by the concussion and to ascertain what symptoms are exacerbated by the concussion [21, 224]. This is similar for sport participants with learning disabilities such as attention deficit disorder/attention deficit hyperactivity disorder and migraines [50, 71, 84, 108, 132].

### 3.10 Effects of Multiple Concussions

Following a concussion, the sport participant's risk of a subsequent concussion is increased, especially in the 7- to 10-day period following the acute injury [19, 57, 216]. There is a sixfold increase in the risk of sustaining a subsequent concussion for athletes who experience a loss of consciousness, compared with those who have no loss of consciousness [57]. The reasons for this have not been fully elucidated but may be related to (a) the style of play predisposing them to another injury; (b) susceptibility of the athlete; (c) age and level of participation; (d) the possibility that the athlete may receive more exposure time; or (e) the fact that once a concussion occurs, the brain is more susceptible to a concussive injury [57]. Athletes with prior concussions may take longer to recover from an acute concussive injury [19].

The effects of repeated concussions are reportedly cumulative and permanent [15, 19, 81, 110, 122, 216, 218, 223, 262]. These effects range from an increased risk of a repeat concussion (5.8 times), on-field loss of consciousness (6.7 times), confusion (4.1 times) and anterograde amnesia (3.8 times) with each subsequent concussion [15, 19] through to decreased performance in attention, concentration, immediate memory recall and visual motor coordination [214]. These effects can be more pronounced if the period between concussions is shorter and the effects are additive [262]. Some [15, 81, 110] but not all [5] researchers have identified that athletes with multiple concussions report more symptoms and have a worse neuropsychological test performance than athletes with no history of concussions. This might be reflective of the cumulative and additive effects of multiple concussions [268], with resolution of the symptoms occurring over a period from several days to months to years, or they may be permanent [15, 19, 272].

A reported but extremely rare and controversial condition that can occur as a result of a subsequent concussion is second-impact syndrome [254, 265]. Second-impact syndrome is reportedly more common in children and adolescents younger than 21 years old [254, 271]. Re-injury need not occur on the same day and has been reported to have occurred within up to 2 weeks following the first concussive injury [265]. The second injury may initially appear to be of the mildest degree but can quickly evolve to collapse, loss of consciousness and respiratory failure, and death may occur [211]. These events have been attributed to cerebrovascular dysregulation, vascular engorgement, herniation of brain tissue, worsening cellular metabolic changes and more significant cognitive deficits [63, 95, 137, 141, 142, 254, 271], although the exact pathophysiological pathway remains unknown [161, 167].

More recently, it has been reported that multiple concussions may be linked with CTE [23, 105], but there is a paucity of published studies, and it is not possible to determine if there is a cause-and-effect relationship between concussions or exposures to contact sports [3, 24]. CTE has been found in athletes as young as 18 years who have died with a history of concussions [290]. Athletes with multiple concussions can have neurobehavioural manifestations of CTE, such as changes in memory, behaviour, personality, gait and speech, similar to Parkinsonism-type symptoms [23, 105]. Although concussion has been described as a risk factor for CTE [291], what is not known is whether this may be caused by concussive and/or subconcussive events, the frequency of these types of events to occur for CTE to develop, and if there is a predisposition for only a small number of athletes to be at risk of having CTE [6]. More studies are required to determine if there is a direct causal link between concussion and CTE [3, 24], at what age the nervous system is most susceptible to the effects of concussion, and whether proper management of concussion can reducing late-life neurodegenerative dementias [6].

Not all injuries to the head will result in concussion. In situations where the brain is exposed to forces (linear and/or rotational), it is difficult to reliably identify non-concussive episodes [133]. High school football players have recorded significant neurophysiological changes despite having no clinical symptoms of concussion [136]. This was further identified in rats that underwent a subconcussive lateral fluid percussion [127]. The percussion resulted in a neurophysiological change but did not affect behaviour or have any other injury severity measures such as loss of consciousness [127]. Further research is therefore warranted for the monitoring of subconcussive injuries in several areas, to identify (1) tools that are available to assist in the identification of subconcussive injuries; (2) how often subconcussive incidents occur in contact sports such as rugby league and rugby union; and (3) what changes occur over a period of repeated subconcussive incidents.

### 3.11 Return to Play

The use of RTP guidelines has been based around the biomechanical concepts of concussion [269]. The first reported RTP rule was the 'three strike rule' originally proposed by Quigley [256] in 1945 and then adapted by Thorndike in 1952 [256]. This rule recommends that if an athlete has three concussions, then they should terminate future sport participation [233]. Subsequent RTP guidelines (see Table 2) extended and expanded Quigley's rule and were established with the intention of preventing catastrophic injuries and cumulative effects that may occur as a result of concussion [228].

All of the established guidelines focused on ensuring that the sport participants must be free of any post-traumatic amnesia symptoms and post-concussion symptoms both at rest and during exercise [209]. The original RTP guidelines were based on either clinical experience [210] or the result of a catastrophic incident [185, 188]. In the mid-1990s, these guidelines were critiqued regarding their scientific basis, resulting in a workshop to re-evaluate the guidelines and establish practical alternatives [272]. The guideline published as a result of this workshop did not differ substantially from previous guidelines but started the move from numerical grading to individualized management of concussions [247].

More recently, the CISG identified that none of the published RTP guidelines were adequate to assure proper management of every concussion [187]. The CISG [3, 13] also published a graduated RTP protocol (see Table 3) for a stepwise process of rest to exertion for returning the athlete to the sporting environment, separated by at least 24 h between the different stages. RTP should be individualized to the concussed player, utilized in conjunction with symptom assessment and cognitive examinations, and used for tracking the recovery of the concussed player [19, 63, 99, 172, 193, 195, 242]. The RTP protocol is appropriate for children and adolescents as young as 10 years [13]. Athletes under the age of 18 years would require a more conservative RTP protocol, while athletes under the age of 10 years would require age-appropriate symptoms checks [13].

On the basis of SCAT2, the International Rugby Board (IRB) has developed online resources for both the healthcare provider and non-healthcare provider (http://www.irbplayerwelfare.com/?documentid=module&module=1) in the assessment and management of a concussed athlete, utilizing the consensus statement and its associated assessment tools. The IRB also introduced a 'Pitch-Side Concussion Assessment' (PSCA) for use in the World U20 IRB competition (2012) and in professional competitions (2013) but, again, there have been no published studies reporting on this as a sideline protocol for assessment of concussion. PSCA is undertaken in a 5 min concussion bin period but is well short of the CIS guidelines of 15 min for sideline concussion assessment [191]. To date, there are no published studies reporting the effectiveness of these implementations in the identification and management of rugby-related concussive events.

Compliance with RTP regulations has been reported to be poor. Players with a reported concussion undertaking the required stand-down regulations have varied from 33 % [33] to 100 % [77] non-compliance, despite receiving RTP advice. With the recent CIS Conference, the newly produced SCAT3 [3] has altered the RTP requirement for medical clearance. SCAT2 [13] identified that with RTP, there should be 24 h (or longer) between stages and that medical clearance should be given before RTP. SCAT3 [3] differs from RTP, as athletes should now "be medically cleared and then follow a stepwise supervised program, with stages of progression", where there should be 24 h (or longer) between stages, and medical clearance should be given before RTP.

### 3.12 Linear and Rotational Head Acceleration–Deceleration

A concussion typically occurs as a result of a direct impact to the head or from an indirect impact applied to the body that is transmitted to the head [13, 187, 194, 259]. This results when the torso is either decelerated or accelerated rapidly [181]. Consequently, the head sustains a combination of linear and rotational acceleration. Direct impacts with the head (linear acceleration–deceleration) and inertial loading of the head (rotational acceleration–deceleration) have been postulated as the two major mechanisms of head-related injuries such as concussion [181]. Linear acceleration produces focal injuries, while rotational acceleration produces both focal and diffuse injuries [181].

Denny-Brown and Russell [219] first described concussion as a result of sudden velocity changes, terming this 'linear acceleration–deceleration'. Considered as the most important mechanism of head injuries, linear impact forces were attributed to intracranial damage resulting in pressure gradients and deformation of the skull, which were the key factors for a concussion occurring [45, 181, 229]. Although pressure within the brain varied during an impact, there

**Table 3** Fourth Concussion in Sport Group (CISG) graduated return-to-play protocol [3]

| | Rehabilitation stage | Functional exercise at each stage of rehabilitation | Objective of each stage |
|---|---|---|---|
| 1. | No activity | Physical and cognitive rest | Recovery |
| 2. | Light aerobic exercise | Walking, swimming or stationary cycling, keeping intensity <70 % of maximum predicted heart rate; no resistance training | Increase in heart rate |
| 3. | Sport-specific exercise | Skating drills in ice hockey, running drills in soccer; no head impact activities | Add movement |
| 4. | Non-contact training drills | Progression to more complex training drills, e.g. passing drills in football and ice hockey; may start progressive resistance training | Exercise, coordination and cognitive loading |
| 5. | Full contact practice | Following medical clearance, participate in normal training activities | Restore confidence and assess functional skills by coaching staff |
| 6. | Return-to-play | Normal game play | |

was a strong correlation ($r^2 = 0.42$) between linear acceleration and brain deformation [263]. Concussive events that occurred during a linear acceleration–deceleration were the result of the brain's relatively low inertia being unable to keep up with the movement of the skull [230]. Also, acceleration per se was not the primary cause of injury, as rapid motion causes displacement of the hard bony structures of the skull against the soft tissues of the brain [145]. Primarily because of limitations in techniques and equipment being available to measure rotational acceleration [258], the linear acceleration–deceleration hypothesis has been the most frequently measured.

In 1945, Holburn [235] first stated that concussions were a result of rotational movements with or without direct impact, and termed this 'rotational acceleration'. It was later proposed that rotational acceleration was the cause of gliding contusion resulting from excessive strain of the cerebral blood vessels [97]. Rotational acceleration was reported to contribute more than linear acceleration to concussive injuries, diffuse axonal injuries and subdural haematomas [181]. Rotational or shear forces applied to the head deform brain tissue more readily than any other biological tissues, and this is the predominant mechanism of injury in concussion [259, 261]. Rotational acceleration–deceleration may contribute to, and is linked with, cytoskeleton damage in animal models of concussion [45, 244].

### 3.13 Forces Associated with Concussion

There is limited published research on the forces associated with concussion (see Table 4). The majority of the data have come from American football matches at various levels of participation by on-field monitoring, and using impact reconstruction of concussive impacts [101, 116, 117, 144, 145]. In laboratory reconstructions, it was reported that concussive events have occurred with face mask linear accelerations of 78 ± 18 *g* [116] to 94 ± 27 *g* [181], but greater accelerations were recorded on other areas of the head, with an average of 107–117 *g* [116]. Using a helmet telemetry system, real-time head acceleration measurements were recorded for high school football players, with peak linear accelerations varying from 55.7 to 136.7 *g* for concussive events [46]. This was extended further with the helmet telemetry system monitoring impacts in collegiate football players, with peak linear accelerations ranging from 60 to 120 *g* for concussive events, with the majority of peak accelerations being above 95 *g* [38, 39, 74, 229].

Laboratory reconstructions have also provided rotational accelerations [116, 117, 145, 181]. In duplicating National Football League (NFL) concussive events, rotational accelerations of 6,398 ± 1,798 radians per second (rad/s$^2$) occurred for concussive events [181]. Studies using the helmet telemetry systems on high school football players measured rotational accelerations of 163.4–8,994.4 rad/s$^2$ over 7–16 ms [38, 39, 44, 101] when concussive events occurred, while collegiate football players recorded higher rotational accelerations of 5,582–9,515 rad/s$^2$ [38, 74]. Findings were similar in comparisons of collegiate football (7,092 ± 1,214 rad/s$^2$ over 9.6 ± 2.8 ms) [44] with NFL (6,569 ± 1,866 rad/s$^2$ over 9.7 ± 1.7 ms) [144]. Utilizing a logistic regression analysis on previously published data [117], there was a 75 % chance of a concussion occurring [181] when an event occurred that resulted in linear acceleration of 98 *g* combined with rotational acceleration of 7,130 rad/s$^2$ [58]. Unfortunately, not all studies reporting impact forces associated with concussive events have provided linear, rotational and impact duration data. From the studies that have reported all of these components, it can be seen that the force duration associated with concussive events varies by participation level.

Helmets that are used in these sports have some protective effect in regard to concussive events [181]. When conducting hybrid head tests with helmets for impact reconstruction, there was a 21–29 % reduction in linear accelerations but an

**Table 4** Linear and rotational forces, impact duration and standard deviations associated with non-concussive and concussive events

| References | Sports code | No. of concussions | Session type (no. of impacts[a]) | Linear acceleration (*g*), (mean ± SD) | Rotational acceleration (rad/s$^2$), (mean ± SD) | Impact duration (ms), (mean ± SD) |
|---|---|---|---|---|---|---|
| Non-concussive impact forces | | | | | | |
| Broglio et al. [44] | High school football | N/A | Practice (29,287) | 24.8 ± 14.8 | 1,569.8 ± 1,124.8 | 10.2 ± 3.8 |
| | | N/A | Game (25,312) | 26.7 ± 17.1 | 1,728.9 ± 1,319.3 | 10.2 ± 3.6 |
| Guskiewicz et al. [74]; Guskiewicz and Mihalik [229] | Collegiate football | N/A | Game (104,714) | – | – | – |
| Duma et al. [58] | Collegiate football | N/A | Practice (2,114) | 32 ± 25 | 905 ± 1,075 (*x*-axis) | - |
| | | N/A | Games (1,198) | 32 ± 25 | 2,020 ± 2,042 (*y*-axis) | - |
| Reed et al. [123] | Bantam ice hockey | N/A | Games (2,989) | 22.1 ± 0.4 | 1,557.4 ± 26.9 | - |
| Viano and Pellman [144][b] | NFL | N/A | Game | 67.8 ± 14.7 | 4,847.6 ± 929.8 | 7.9 ± 1.9 |
| Pellman et al. [116][b] | NFL | N/A | Laboratory[b] | 59.7 ± 23.9 | 4,234.7 ± 1,716.3 | 7.1 ± 2.6 |
| | | N/A | Laboratory[c] | 56.2 ± 22.2 | 3,982 ± 1,402 | 9.3 ± 1.9 |
| Brolinson et al. [46] | Collegiate football | N/A | Game (11,604) | 20.9 ± 18.7 | – | – |
| | High school football | N/A | Game | 29.2 ± 1.0 | – | – |
| Naunheim et al. [111] | High school hockey | N/A | Game | 35.0 ± 1.7 | – | – |
| | High school soccer | N/A | Game | 54.7 ± 4.1 | – | – |
| Concussive impact forces | | | | | | |
| Broglio et al. [44] | High school football | 2 | Practice (3.5 ± 2.1[d]) | 105.9 ± 19.5 | 7,982.2 ± 21.3 | 10.0 ± 1.4 |
| | | 11 | Game (19.7 ± 21.3[d]) | 100.0 ± 1.3 | 7,092.6 ± 1,214.2 | 9.6 ± 2.8 |
| Guskiewicz et al. [74]; Guskiewicz and Mihalik [229] | Collegiate football | 13 | – | 102.8 ± 32.0 | 5,311.6 ± 4,111.0 | – |
| Duma et al. [58] | Collegiate football | 1 | – | 81 | 7,912 | – |
| Viano and Pellman [144][b] | NFL | 22 | Game | 94.3 ± 27.5 | 6,569.0 ± 1,866.4 | 9.7 ± 1.7 |
| Pellman et al. [116][b] | NFL | 25 | Game | 98.2 ± 28.1 | 6,552.4 ± 1,770.5 | 9.3 ± 1.9 |
| Brolinson et al. [46] | Collegiate football | 3 | Game | 89.1 ± 43.0 | – | – |
| Viano et al. [145] | NFL | 25 | Game (struck) | 98 ± 28 | 6,432 ± 1,813 | 9.3 ± 1.9 |
| | | | Game (striking) | 58.5 ± 21.4 | 4,225 ± 1,405 | – |
| Beckwith et al. [38] | Collegiate and high school | 105 | Competition[e] | 112.1 ± 35.4 | 4,253 ± 2,287 | 4.3 ± 1.7 |
| Beckwith et al. [39] | Collegiate and high school | 105 | Competition[f] | 102.5 ± 33.8 | 3,977 ± 2,272 | 3.7 ± 1.6 |

*g* gravitational acceleration, *N/A* not applicable, *NFL* National Football League, *rad/s$^2$* radians per second per second, *SD* standard deviation

[a] Except where stated otherwise

[b] Laboratory reconstruction of the struck player in NFL collisions

[c] Laboratory reconstruction of the striking player in NFL collisions

[d] No. of impacts (mean ± SD) before concussion

[e] Mean severity of impacts prior to immediately diagnosed concussions

[f] Average peak linear and angular acceleration for all impacts associated with diagnosed concussion

increase in rotational accelerations when compared with the non-helmeted tests [181]. To date, there are no published studies reporting the impact that results in concussive events from participation in non-helmeted sports such as rugby union and rugby league. Further research is warranted to investigate the impacts that occur in concussive events in non-helmeted sports to enable broader understanding of the forces associated with concussion.

### 3.14 Knowledge and Understanding

Several studies have reported on the knowledge and understanding of concussion for team management [60, 83, 85, 113, 135, 143] and parents [60, 134]. Studies reporting coaches' knowledge and management of concussion identified that 16 % [113] to 51 % [143] of coaches were unable to correctly identify factors relating to concussion recognition, management and prevention techniques. Between 40 % [85] and 42 % [143] of coaches thought that a player needed to lose consciousness for a concussion to occur. Over a quarter, 26 % [85] to 32 % [143], would not remove a concussed player from the field of play. Similarly, 20 % [85] to 26 % [143] would let a symptomatic player RTP, and 30 % [85] to 50 % [119] of coaches believed that head-gear could minimize the risk of concussion. In assessing parents' understanding of concussion [134], it was reported that 83 % of parents believed they could recognize a concussion in their teenager, 5 % reported that a player needed to lose consciousness for a concussion to occur, 19 % of parents would not have their teenager see a medical practitioner if there was a suspected concussion, and 4 % would let a symptomatic teenager RTP.

Studies on the effectiveness of concussion education resources, such as the Centre for Disease Control concussion education website, found that 80 % [73] of football coaches identified these as 'moderately useful', 63 % of coaches realised concussions were more serious than previously thought, 50 % of coaches made future changes in regard to dealing with concussion, and 72 % of coaches used the resources to educate other coaches, parents and athletes [4]. Comparison is difficult, as no studies have reported changes in coach and team management awareness and knowledge through the use of concussion education in sporting activities. Future studies reporting the knowledge and awareness of team management are warranted.

### 3.15 Health Practitioner Knowledge and Management of Concussion

Concussion clinical practice guidelines (CPGs) are available [169, 189], but their utilization by health professionals has not been well documented [120]. The quality and consistency of the concussion CPGs have been reported to be lower than those of other medical CPGs [150]. They have considerable variability in the methodological quality, guidance [150, 170] and recommendations [170]. Stakeholder involvement [173, 176] and consideration is limited for the applicability of the recommendations (i.e. cost implications, monitoring procedures, etc.) [173]. In some cases, the guidelines conflicted in the management, which may affect the decision-making process for follow-up and further management [176].

Studies [36, 69, 120] have shown that 27–32 % of the discharge instructions provided to patients agreed with available published guidelines for RTP following a concussion. This was similar for primary care providers, with only 20 % indicating that they utilized guidelines in the management of concussion [120]. Emergency department practitioners' use of concussion guidelines was slightly greater, with 44 % of those surveyed indicating that they utilized a concussion guideline in the management, but there was little consistency in the guideline being utilized [70].

In regard to RTP decisions, there were differences reported for both primary care providers and emergency department practitioners [35, 36, 70, 120, 251]. Of concern was that 7 % of emergency department practitioners would return the patient to the same match, 31 % in 1 day and 27 % in 1 week if asymptomatic. A third (33 %) recommended RTP only after clearance by a physician for an initial concussion, but 67 % recommended this for a subsequent concussion. Twelve percent [112] of primary care providers have been reported to use RTP guidelines, identifying that clinical examination (89–93 %) [54] was the most commonly used method for RTP decisions.

The most common reason for the variations in the management of concussion is lack of awareness of, and confusion with, the many published guidelines that are available [36, 92, 120]. The use of differing guidelines for the assessment and management of concussion may be the primary reason for variations reported in health professional's RTP decisions [70, 120]. The most frequently cited guidelines utilized in RTP decisions by health professionals were the American Academy of Neurology, Colorado Medical Society Guidelines and Cantu guidelines [70, 120]. The new guidelines indicate no RTP when a concussion is diagnosed or suspected. We need adherence to these guidelines in the sporting context.

To date there is a paucity of research on emergency department and primary care practitioners' management of concussion. An advice card may be given out with information on when to RTP if symptoms return or persist—but once a structural injury is ruled out, little consideration is provided to the functional brain injury.

Additionally, a lot of the published research reporting on primary care providers and emergency department management of concussion was prior to the publication of the third CISG guidelines and the recent increase in concussion awareness. Further research is warranted to explore these areas to assist in the development of evidence-based information for this group of health practitioners. Until this evidence is available, the decision will remain a clinical one, utilizing the guidelines from the new consensus statement in April 2013 that advocate the use of the King-Devick visual test, clinical reaction tests with the new systems of SCAT3, Child-SCAT, a concussion recognition tool and other neuropsychological testing systems.

### 3.16 Academic Considerations

There is a paucity of studies reporting on academic-level sport participants and the management of the individual with a concussion on reintegration into the academic environment. To date, there are no published standardized guidelines for the return of a sport participant to academic studies [193]. From the studies reporting on the academic consequences of concussion, it has been reported that students may struggle to concentrate, may fail to perform academically, and may have verbal and memory learning difficulties [91, 110, 257]. Students with two or more concussions and a learning disability had significantly worse executive functioning and speed of mental processing test results, when compared with students with a similar concussion history and no learning disability [50]. Persistent neurocognitive difficulties were reported in high school athletes with two or more concussions [110]. These students had lower cumulative academic grade averages, and it was uncertain whether this was as a result of the concussion history, a characteristic of predisposition for concussion or a combination of both of these factors [110].

It has been recommended that a period of cognitive rest is needed to prevent exacerbation of the symptoms of concussion [109, 232, 257, 260]. This may include a leave of absence from the school environment [109, 236, 257, 260], shortening of the academic day, reductions in workloads in school and allowance of more time to complete assignments or tests [109, 240, 257, 260]. Although there are some studies reporting on the effects of concussion at high school-level [110], collegiate-level [41] and secondary-level [91] academia, there are no published studies to date on lower levels of academia nor on academic institutions outside the USA. Additional resources to help explain student academic issues as a result of concussion should be developed for both clinicians and educators [193]. Future research into the return-to-academia procedures is warranted.

### 3.17 Implications for the Assessment and Management of Concussion

The prevention of concussions should be a priority, as athletes will always be exposed to head impacts [227]. The incidence can be mitigated to some degree by education of athletes [42], coaches and team management [85, 113, 143], family members [106] and health professionals [36, 48, 178]. Development of up-to-date educational resources is a priority to enable dissemination of appropriate up-to-date information for all people involved in the identification and management of a concussion. Although there are resources available through various international sources [4, 48], individual sporting codes should also be responsible for the dissemination of this information to participants, volunteers, medical personal and family members.

Often players do not recognize that a concussion may have occurred, with as few as 23 % reporting symptoms that may represent a concussion [18]. McCrea et al. [104] identified that only 47 % of high school football players reported having sustained a concussion during match or training activities. Often the assessment and management of concussions relies upon visual cues to a concussion occurring, such as head clashes, player stumbling, loss of consciousness or players reporting they have had a concussive event [123]. Consequently, a number of concussions remain unnoticed [58, 147].

Head impact systems are effective at recording head accelerations during various sporting activities [46, 58] and have been used to assist in the development of injury tolerance curves, severity indices and identification of individual players requiring further medical assessment. Despite this technological development, head impact telemetry systems are not a diagnostic tool for the assessment of concussion [46] but can assist in identification of potentially concussed players needing further medical assessment. By monitoring players through a head impact telemetry system, medical personnel can monitor the impacts that players receive and have a visually recorded cue, should an unreported or unwitnessed concussive event occur. This technology is in its infancy and may well be out of reach of amateur-level sport participation, but research at higher levels of sport participation may be beneficial to identify the impacts that do occur. As the published literature is limited to a few sports (e.g. ice hockey [123], football [46, 58], soccer [75]), further longitudinal studies are warranted in a wider spectrum of sports to assist in broadening knowledge of the effects of impacts in sports and concussion.

Management of concussion varies depending on the knowledge of the practitioner and the information and resources that are available to assist with decision making [36, 120]. Information provided to the individuals can vary [36, 120], and this may unwittingly place the person with a concussion at risk of a more serious injury should they receive another concussion [35, 36, 69, 70, 120, 251]. Although research has been increasing in recent years and the information available changes, medical facilities and sporting organizations need to provide the most appropriate up-to-date identification, management and return-to-sport protocols to sport participants. This may require regular reviews of the policies and standards available to ensure these are current. For example, the TBI guideline [169] available to health practitioners in New Zealand was produced in 2007 and, despite the publication of the CISG consensus statement, this has not been revised nor have there been any updates to this guideline.

Diagnosing a concussion represents a significant clinical challenge [227]. Often concussion severity and significance cannot be definitively determined until symptom resolution [227]. Sideline injury screenings employ symptom checklists, cognitive tests and balance evaluations that are reasonably sensitive, and specific, for the initial identification of a concussion [66, 67]. This is dependent upon two critical factors: (1) the player must be identified as having a suspected concussion; and (2) someone must be available to conduct the screening process [227]. If either of these factors is not present, then there is a risk of a suspected concussion being missed [227]. At the amateur level, this is often the problem, and more than 50 % of concussions remain unreported [104]. To assist in reducing the number of missed concussions, sports codes could include specific concussion assessment educational sessions, make sideline assessment tools readily available and encourage use of appropriately trained qualified personnel in head injury management at all levels of participation.

The effects of multiple or repetitive concussions are not well understood but are currently being researched [227]. There is animal study evidence of the brain's increased vulnerability to structural and/or functional damage following a concussive injury [227, 244]. There is anecdotal evidence that recent concussive impacts increase the likelihood and severity of functional impairment to the brain [21–23]. There is a strong connection [220] between the effects of concussion, especially repeat concussion, and brain function decline [21, 214] such as the progressive neurodegenerative syndrome and CTE [290]. This may be caused by either a single, an episodic or repetitive blunt force impacts to the head.

Although research into CTE, and its connection to concussion, is in its infancy [207], it is proposed that widespread monitoring of concussion should occur at all levels of participation [227]. This should be done for concussive as well as sub-concussive incidents. This has the potential to enhance the identification of a concussive event and may assist in the reduction of underreporting [227].

## 4 Conclusions

Concussion still remains a mystifying subject in the sports medicine arena. The underreporting of concussion makes identifying the true incidence difficult, and makes diagnosis and management of concussion a challenge. The pathophysiological effects of a concussion can be seen from within 24 h of the event, occurring up to several weeks post-injury. As a result of increased metabolic dysfunction, the brain has increased vulnerability to other consequences. A concern with the reporting of concussion is that studies have utilized different definitions, methodologies (retrospective and prospective) and reporting modalities. The CISG has made advances in the identification and management of concussion; however, until the CISG definition of concussion is universally used by all researchers, the true incidence and cost of concussion will not be known.

Symptoms of concussion are variable, and measurement of these symptoms depends on self-reporting. The CISG has produced SCAT3, representing the newest sideline concussion assessment tool to date. More recently, the King-Devick test has been used successfully to identify concussion. Initial sideline assessment should be undertaken to identify the athlete with a concussion, but this should only be part of a continuum of assessment modalities. More advanced assessments such as SCAT3 and Child-SCAT3 can then be undertaken to further evaluate the player with a suspected concussion. The use of head impact telemetry for head impacts has been shown to be an effective measurement tool. By monitoring players through an impact telemetry system, medical personnel can monitor the impacts that players receive and have a visually recorded cue when unreported or unwitnessed potential concussive events occur, but this will be beyond the financial capacities of many amateur sporting activities. Sports medicine practitioners should be cognisant of the extent and nature of concussion and should work with coaches, athletes and trainers to identify and manage concussions.

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