Beyond acute concussion assessment to office management: a systematic review informing the development of a Sport Concussion Office Assessment Tool (SCOAT6) for adults and children

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ABSTRACT

Objectives To systematically review the scientific literature regarding the assessment of sport-related concussion (SRC) in the subacute phase (3–30 days) and provide recommendations for developing a Sport Concussion Office Assessment Tool (SCOAT6).

Data sources MEDLINE, Embase, PsycINFO, Cochrane CENTRAL, CINAHL, SPORTDiscus and Web of Science searched from 2001 to 2022. Data extracted included study design, population, definition of SRC diagnosis, outcome measure(s) and results.

Eligibility criteria (1) Original research, cohort studies, case–control studies, diagnostic accuracy and case series with samples >10; (2) SRC; (3) screening/technology that assessed SRC in the subacute period and (4) low risk of bias (ROB). ROB was performed using adapted Scottish Intercollegiate Guidelines Network criteria. Quality of evidence was evaluated using the Strength of Recommendation Taxonomy classification.

Results Of 9913 studies screened, 127 met inclusion, assessing 12 overlapping domains. Results were summarised narratively. Studies of acceptable (81) or high (2) quality were used to inform the SCOAT6, finding sufficient evidence for including the assessment of autonomic function, dual gait, vestibular ocular motor screening (VOMS) and mental health screening.

Conclusion Current SRC tools have limited utility beyond 72 hours. Incorporation of a multimodal clinical assessment in the subacute phase of SRC may include symptom evaluation, orthostatic hypotension screen, verbal neurocognitive tests, cervical spine evaluation, neurological screen, Modified Balance Error Scoring System, single/dual task tandem gait, modified VOMS and provocative exercise tests. Screens for sleep disturbance, anxiety and depression are recommended. Studies to evaluate the psychometric properties, clinical feasibility in different environments and time frames are needed.

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WHAT IS ALREADY KNOWN?

- ⇒ The Sport Concussion Assessment Tools (SCAT and Child SCAT) have evolved over five iterations having optimal utility in the first 72 hours (3 days) and up to 7 days following sport-related concussion (SRC).
- ⇒ The effects of SRC often last several days to weeks, with athletes presenting for assessment to a range of healthcare professionals (HCPs).
- ⇒ Evaluation of SRC requires multimodal and often multiple time point assessments to evaluate the domains involved and guide individualised management.
- ⇒ A freely accessible comprehensive office assessment tool can aid clinicians in identifying tests and domains to be assessed when performing a multimodal clinical assessment of athletes with SRC.

WHAT ARE THE NEW FINDINGS?

- ⇒ Several clinical tools are useful in distinguishing concussed athletes from non-concussed controls in the days and weeks following SRC.
- ⇒ Most clinical tests evaluate a specific domain potentially affected by concussion.
- ⇒ The Sport Concussion Office Assessment Tool 6 (SCOAT6)—Adolescent/Adult and Child versions—combines clinical tests with demonstrated validity for concussion to enable HCPs to perform a more comprehensive multimodal assessment in an office environment.
- ⇒ The SCOAT6 requires further evaluation to understand the validity and clinical utility at various timepoints postinjury and in different age groups and clinical settings.

INTRODUCTION

The Concussion in Sport Group (CISG) developed the concept of a standardised and systematic

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clinical evaluation for healthcare professionals (HCP) known as the Sport Concussion Assessment Tool (SCAT) in Prague 2004.[1] The SCAT evolved through various iterations at each successive consensus meeting. The SCAT5 was numbered to align with the fifth consensus meeting.[2] Since 2012, a version for children 12 years and under has also been published, the Child SCAT.[3] Collectively known as the SCAT tools, the SCAT and Child SCAT have always been freely available and designed such that minimal equipment is needed.[4 5] The purpose of the SCAT and Child SCAT is to assist in the detection of acute concussion; these tools are most appropriately used on the sideline and within the first 3 days of injury, with diminishing utility up to day 7.[6 7]

Concussion is a complex pathophysiological process, heterogeneous in nature with possible symptoms and signs across multiple domains, which may evolve over time.[8 9] Inconsistency in the evaluation of concussion has been acknowledged, with a need to include assessment of multiple clinical domains including neurological, vestibular, balance, oculomotor, visual, neurocognitive, psychological and cervical spine.[9] Moreover, many sport-related concussions (SRC) may present to HCPs outside of the sports environment such as in the emergency room, or to family practitioners, paediatricians or other medical disciplines in the days following concussion. In these contexts, the approach necessitates including a more detailed evaluation of the history, a multimodal clinical assessment, identification of prognostic markers, and initiation of strategies to facilitate short-term and long-term management of concussion.

The intention of the SCAT6 is to assist in the detection of SRC. The sensitivity of most individual components in previous iterations of the SCAT have been shown to decline after the first 72 hours (3 days) following a concussion, the utility of the tool diminishing thereafter.[10 11] The purpose of this systematic review was to inform the development of a Sport Concussion Office Assessment Tool (SCOAT) aligned with the 6th International Conference on Concussion in Sport, to provide HCPs managing athletes with concussion a more expansive, standardised and age-appropriate clinical guide to multimodal evaluation of the concussed athlete in the subacute phase (for the purpose of this review defined as 72 hours to 30 days postinjury). Hence, the review evaluated assessment elements that could be added to the SCAT6 that would be relevant to both the office setting and a more extended time frame. In some cases, a SCAT may have been performed, but in many the office assessment may be the initial evaluation that aids diagnosis and informs management. To date, the literature lacks a tool that brings together assessment outcomes to identify clinical domains that may be affected by SRC and monitor recovery after the initial days following SRC.

This systematic review evaluated clinical elements potentially applicable to the evaluation of subacute SRC as well as emerging technologies that may be of pragmatic relevance. It was intended to inform the Amsterdam Consensus Statement on Concussion in Sport by answering the question, 'What tests, measures and technology most accurately facilitate subacute diagnosis in children and adults who have suffered a suspected SRC?' and thereby inform the development of the SCOAT6.

METHODS

This systematic review followed Cochrane Collaboration recommendations[12] and was reported according to Preferred Reporting Items for Systematic Reviews and Meta-analyses 2020 guidelines[13] (figure 1). In consultation with a research librarian (ZP), lead author (JP) and coauthors, the search strategy was developed using subject headings, keywords, database operators and Boolean operators, translated for each database (online supplemental tables 1 and 2).

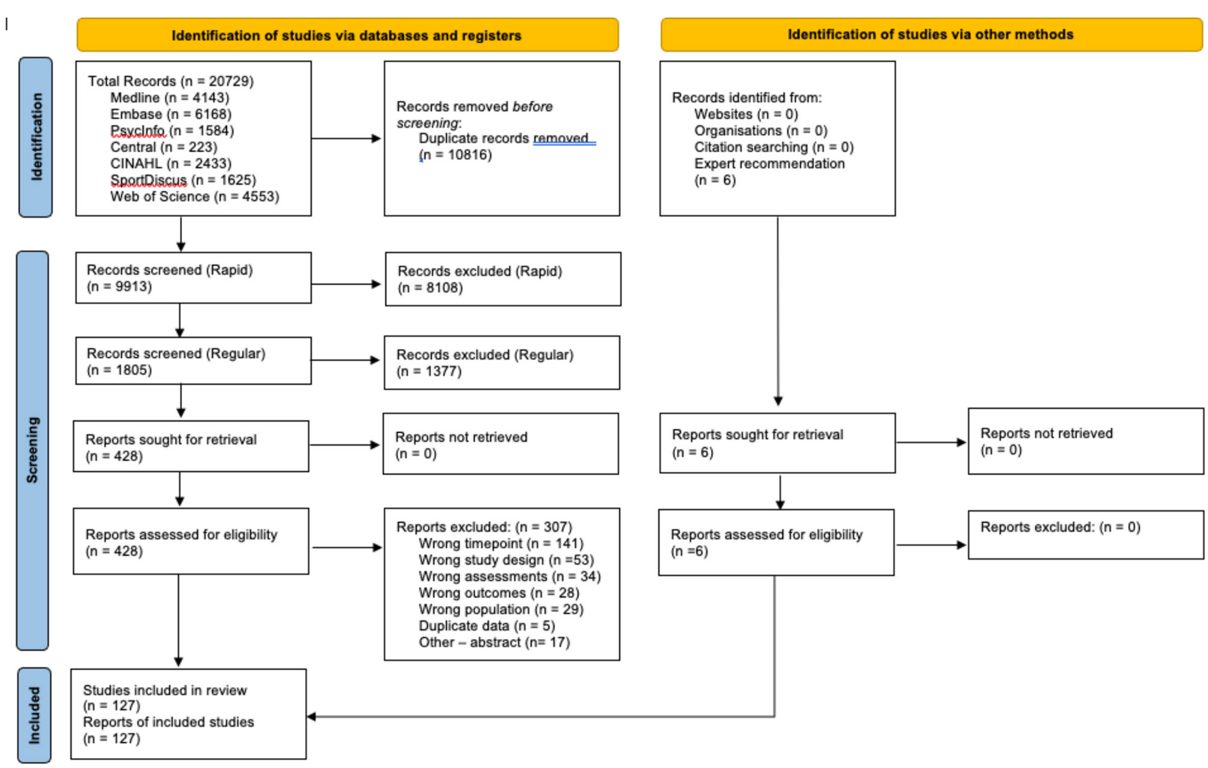

Figure 1 Modified PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.

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Eligibility criteria

Inclusion criteria were: (1) original research (randomised controlled trials, cohort, case cross-overs, case–control, quasi experimental study designs involving humans); (2) SRC (ie, not injuries sustained in other contexts/settings); (3) between 72 hours and 30 days postinjury; (4) English language; (5) peer-reviewed; (6) evaluated clinical assessment measures for subdomains that could be affected by concussion and (7) assessed instruments and technology that could assist in evaluating SRC symptoms and syndromes. Articles were excluded if they evaluated non-SRC; were review articles, commentaries, editorials, expert consensus studies; published in abstract form only; were books, book chapters, conference abstracts or dissertations/theses, or were assessed as having a high risk of bias (ROB). The time frame was the period beyond which existing tools have less utility (72 hours) and up until the athlete may be classified as having 'persisting symptoms' (30 days). During this time, evaluation of SRC would typically be by a HCP in an office setting.

Outcomes

The primary outcome was the diagnostic accuracy of a test to predict: (1) the diagnosis or prognosis of concussion (sensitivity, specificity, likelihood ratios) and (2) affected clinical subdomains related to impairment and function of the patient in the subacute phase of injury.

Data sources

Seven electronic databases (1 January 2001 (to correspond with the start of the international concussion meetings) to 26 March 2022) MEDLINE, Embase, PsycINFO, Cochrane CENTRAL, CINAHL, SPORTDiscus and Web of Science) were systematically searched (online supplemental tables 3–8) and supplemented by searching websites, reviewing the reference lists of relevant systematic reviews and eligible studies, and through expert recommendations. Identified citations were imported into Covidence for deduplication and screening.

Study selection

A 'rapid screen' of all titles/abstracts to remove citations clearly not relevant to SRC, not in humans, or not original research was performed by GS. Coauthors (GMS, JP, KH and KJS) pilot tested 50 randomly selected citations for interrater reliability and revised eligibility criteria where this was less than 80%. Pairs of coauthors (one methods author with methodological expertise and one coauthor) then independently screened remaining titles/abstracts for potential inclusion, and reviewed full texts. Reasons for exclusion were recorded.[14]

Data extraction and ROB

A standardised data extraction table was developed a priori with contributions and approval from all authors, then piloted and reviewed by the authorship team. Following standardised training (both overall and specific to this review), independent pairs of coauthors extracted data into a standardised form in Microsoft Excel. Study authors were contacted where additional information was necessary to assess study outcomes or eligibility.

ROB was assessed by two independent reviewers (one methods author and one coauthor) using adapted Scottish Intercollegiate Guidelines Network[15] criteria according to study design.[14] Disagreements between reviewers were resolved by discussion or by the lead author (JP) when consensus could not be reached. Given the heterogeneity of the literature identified, the Strength of Recommendation Taxonomy was deemed to be the most appropriate means of assessing the overall quality and consistency of evidence in included papers and was applied (KJS) and reviewed by all coauthors.[16] Consistent and good quality patient-oriented evidence is rated 'A'; inconsistent or limited quality patient-oriented evidence, 'B' and consensus, usual practice, opinion, disease-oriented evidence or case series for studies of diagnosis, treatment, prevention or screening, 'C'.

Analysis

Due to differences in study designs, study participants and assessments, meta-analyses were not possible; therefore, we synthesised results narratively across 12 prespecified clinical domains including: (1) global symptom scales, (2) cognition, (3) vestibulo-ocular, (4) cervical assessment, (5) neurological examination (6) autonomic dysfunction, (7) paediatric-specific (8) balance assessment/postural stability, (9) sleep assessment, (10) depression/anxiety, (11) exercise stress test and (12) emerging technologies for office assessment. Where possible, we have provided estimates of sensitivity, specificity and negative and positive predictive values for each clinical domain in addition to the reference standard used.

Equity, diversity and inclusion statement

We included all eligible studies in the systematic review regardless of sample characteristics, including sex, gender, race/ethnicity, socioeconomic level or representation from marginalised groups. Our data extraction forms included these characteristics if provided in the original articles. The authors of this review include both women and men, a former Para athlete, a variety of disciplines, a broad range of career stages and persons of colour. Consistent with the vision of the CISG, we acknowledge the need to strive for greater inclusivity in SRC research.

RESULTS

Following deduplication, 9913 titles and abstracts were screened for possible inclusion with 429 studies progressing to full-text review. Ultimately, 127 studies were included in the final review. These included 61 prospective cohort studies, 12 retrospective cohort studies, 10 case–control studies, 14 case series and 30 cross-sectional studies. While studies were included if participants were assessed between 3 and 30 days for the median or mean timepoints, the range of assessment timepoints varied widely across the studies from 2 to 90 days. With respect to ROB, 2 (1.6%) studies were deemed of high quality, 81 (63.8%) studies were deemed acceptable and 44 (34.6%) studies were deemed inadmissible and excluded from the in-text tables but are available in the online supplement (figure 2 and online supplemental table 10). Acceptable and high-quality studies were used to inform selection of tests to be included in the SCOAT6. Strength of recommendation is presented in table 1. A summary of the SCOAT development process is available in an editorial accompanying the tool.[17] For clarity, results are discussed and tabulated by domain, although several studies overlapped in domains assessed.

Global symptom scales

Nine studies (14 257 participants) reported on the effect of SRC on three global symptom scales, including the SCAT symptom list (22 items), the Post-Concussion Symptom Scale (PCSS, 22 items) and Concussion Symptom Inventory (CSI, 12 items),[18] with the PCSS and CSI demonstrating almost identical diagnostic ability area under the receiver operating curve (AUC) at days 1 and 5. Total symptom scores and symptom

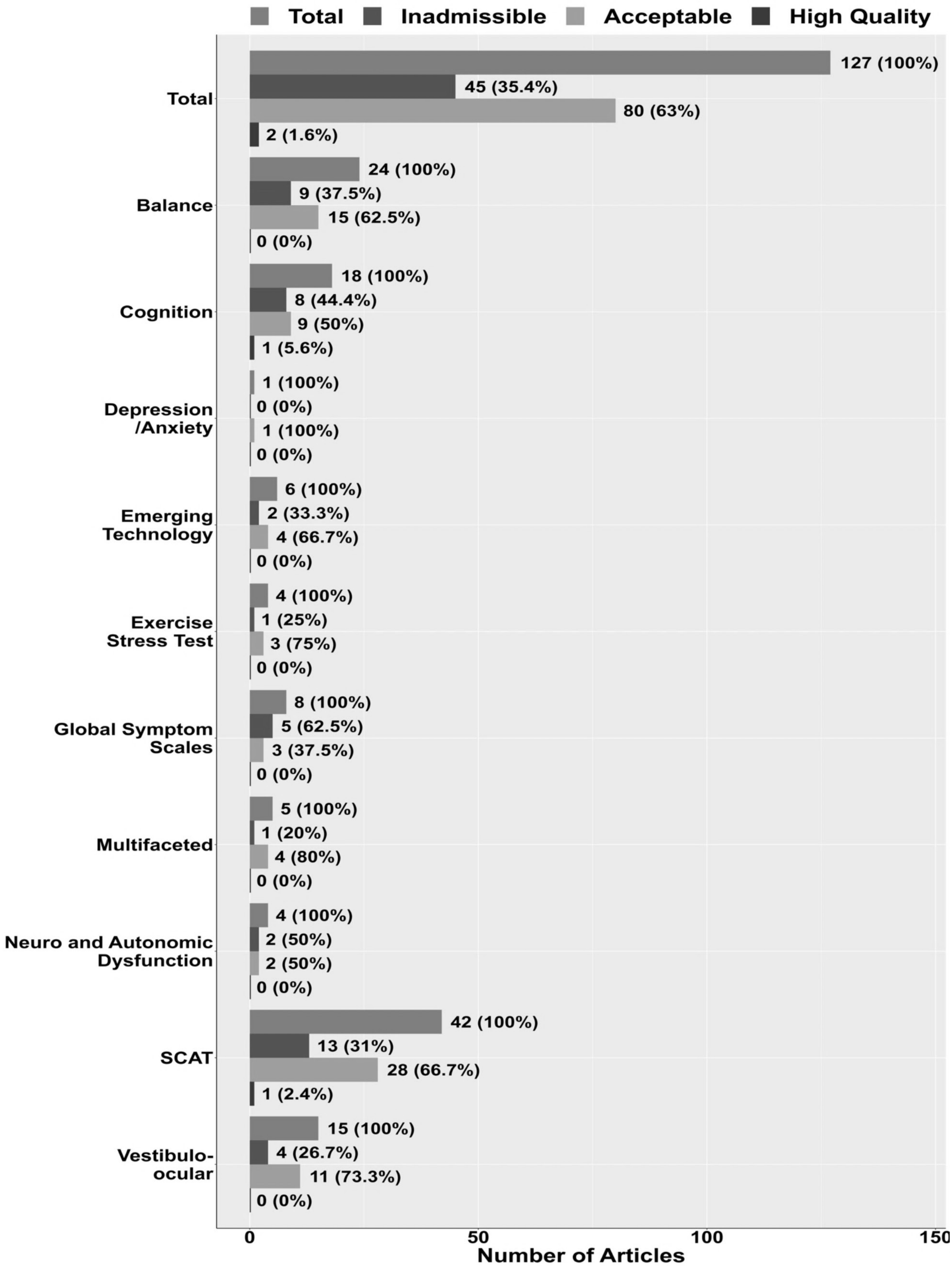

Figure 2 Summary of reviewed article quality by domain.

severity scores reliably distinguished between those with and without an SRC, with the most common symptoms being headache, head pressure, photophobia, phonophobia and 'don't feel right'.[19] Removing emotional and sleep domain symptoms may improve accuracy of the diagnosis of SRC in the subacute time frame.[19]

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Table 1 The Strength of Recommendation Taxonomy (SORT) classification of included studies

Topic	SORT	Recommendations
Global symptom scales	B C	PCSS to assess concussive symptoms in ≥13 years and HBI for 8–12 years (to mirror SCAT6 and Child SCAT6) Include additional symptoms to qualify nature of symptoms
Balance/postural stability	B B B	mBESS as part of SCAT in initial time period (3–5 days); 4 point errors for each component as diagnostic cut point Timed tandem gait (3 m) distinguishes concussed versus controls Dual tasking gait discriminates up to 7–14 days; mark 3 m line for tandem gait with 1 of the following tasks: (1) backward spelling of a 5 letter word; (2) serial subtraction by 7 from a 2 digit number or (3) reciting months in reverse. For children (<12 years): (1) spelling a 4 letter word backwards; (2) serial 3 subtractions; or (3) days of the week backwards.
Cognition	B B	CNTs most useful in early time period and degrade in ability to discriminate concussed and controls at 7–14 days Divided attention tasks may assist in discrimination of concussed/control
Emerging Technology	C	Highly variable, not widely available, costly and of uncertain additional benefit
Vestibulo-ocular	B	VOMS useful as screening tool in subacute time period (0–10 days); only vertical VOR and VMS portion of VOMS at days 8–14; include 4-item version of the VOMS (mVOMS) (smooth pursuits, horizontal saccades, horizontal VOR, VMS)
Depression/anxiety	C	Screening for depression/anxiety using established tools; include PHQ-2, GAD-7 and ASSQ
Exercise stress tests	B	BCTT or BCBT can be used to differentiate concussed and controls 5–10 days after concussion and recommended as an optional inclusion
Multifaceted assessment	B	Multifaceted physical examination to differentiate concussed and controls (including neurological screen, OM, cervical spine assessment, HTT, dynamic balance (including tandem gait), mBESS, neurocognitive testing) up to 10–14 days postinjury
SCAT5/Child SCAT5	B	Most useful early following concussion (<3–5 days) and can be used in absence of baseline test
Divided attention	B	Discriminates between concussed athletes and controls

ASSQ, athlete sleep screening questionnaire; BCBT, Buffalo Concussion Bike Test; BCTT, Buffalo Concussion Treadmill Test; CNT, computerised neurocognitive tool; GAD-7, generalised anxiety disorder 7-item; HBI, health and behaviour inventory score; HTT, head thrust test; mBESS, modified Balance Error Scoring System; OM, oculomotor; PCSS, Post-Concussion Symptom Scale; PHQ-2, patient health questionnaire 2; SCAT5, Sport Concussion Assessment Tools 5; VMS, visual motion sensitivity; VOMS, vestibular ocular motor screening; VOR, vestibular ocular reflex.

Headache severity and frequency, confusion, forgetfulness, attention difficulties, trouble remembering, getting tired often, getting tired easily and dizziness were associated with a longer duration of symptoms,[20] and the presence of headache was associated with cognitive impairment.[21]

Cognition

Twenty-three studies involving 7449 participants evaluated the effects of SRC on cognition. Verbal, paper-and-pencil (P&P) and computerised cognitive tests have been shown to differentiate concussed athletes from non-concussed athletes and musculoskeletal controls during the acute period, with medium to large effects during the first 24–48 hours and with smaller effects for up to 1 week.[22–26]

The Standardised Assessment of Concussion (SAC) contains questions designed to assess an athlete's orientation, immediate memory, concentration and delayed memory, and has been shown to have good sensitivity and specificity, and is part of the SCAT.[23] However, the SAC loses its ability to differentiate between concussed athletes and controls 3–5 days postinjury.[11]

To overcome the ceiling effect of the 5-word verbal recall list contained in previous iterations of the SCAT, the SCAT5 introduced the option of a 10-word list, which has been shown to differentiate between concussed and non-concussed athletes in ice hockey in the early time period following concussion.[26]

Computerised neurocognitive assessment tools (CNTs) have been used for some time, are commercially available, and designed to assist in clinical evaluation of concussion. In a head-to-head case–control study evaluating 3 CNTs (ANAM, Axon and ImPACT) within 24 hours and at 8, 15 and 45 days in high school athletes matched for sport, sex and test scores, CNTs added incrementally to the identification of clinical impairment.[27] Reliable change indices (RCIs) were best at 24 hours, but the effect sizes became smaller at day 8.

A hybrid approach using a CNT and a brief battery of P&P tests was evaluated on 360 professional male ice hockey players.[10] Within a mean time of 12.21 days postinjury, five factors in combination were identified as reliable in evaluating neurocognitive function: P&P measures of verbal learning/memory, visual learning/memory and processing speed/executive functioning, and ImPACT measures loaded on the Cued/Recognition Memory and Reaction Time/Speed factors. However, as the authors point out, it remains to be determined which measures, or combination of measures, best differentiate concussed athletes from controls.

The majority of athletes who experience meaningful neurocognitive decline (measured using CNTs) during the subacute postinjury phase can be identified without baseline data.[28 29] Only impairments of the Simple Reaction Time Test were identified more often using baseline measures.[26]

In high school athletes (aged 15.8±1.34 years) administered ImPACT at baseline and at 2, 7, 14, 21 and 30 days postconcussion, concussed athletes demonstrated a significant decrease in reaction time up to 14 days postconcussion (composite score 0.58, p=0.001) compared with baseline reaction (composite score 0.53).[30] Reaction time returned to baseline levels at 21 days postinjury (p=0.25). At 7 days postinjury, impairments in verbal memory (p=0.003) and motor processing speed (p=0.000) were documented and returned to baseline levels by day 14.

Vestibulo-ocular and oculomotor assessments

Fifteen studies (2487 participants) examined the diagnostic accuracy of the vestibular ocular motor screening (VOMS) test and/or components of the VOMS by using symptom provocation of headache, dizziness, fogginess and nausea in subacute SRC including: (1) smooth pursuit; (2) horizontal and vertical saccades; (3) near point of convergence (NPC) distance; (4) horizontal vestibular ocular reflex (VOR) and (5) visual motion sensitivity (VMS).[31]

Both total and change scores of the VOMS have shown good utility as a screening tool with a sensitivity of 96% in the setting of SRC within the first week, with symptom provocation during VOR and VMS being the most predictive of concussion.[32 33] Optimal cut-off scores have been recommended including ≥2 point of symptom increase for individual VOMS items, ≥3 for overall VOMS change score or an NPC distance of ≥5 cm.[33 34]

Conflicting evidence exists, however, regarding the diagnostic accuracy of the VOMS at 2 weeks postinjury and at return-to-sport (RTS).[35 36]

Cheever evaluated a combination of vestibular and oculomotor tests in a subacute (≤10 days postconcussion) and a prolonged symptom group (≥16 (median=84) days) versus healthy controls at initial evaluation, 2 weeks and 6 weeks.[37] These included gaze-stabilisation, rapid eye horizontal measures, optokinetic stimulation, smooth pursuit slow and fast tests, total combined symptoms scores, NPC and the King Devick test. The study demonstrated that, when combined, vestibular and oculomotor clinical tests have the potential to aid in the detection of SRC.

Neurological examination and autonomic dysfunction

Four studies with a total of 226 participants assessed autonomic dysfunction following SRC.[38–41] Findings from the heart rate variability (HRV) literature suggest possible neuroautonomic cardiovascular dysfunction, with decreased HRV reported with exercise, but not at rest.[38]

Compared with controls, concussed athletes exhibited increased pretesting seated diastolic blood pressure (DBP), and increased heart rate (HR) in supine, sitting and standing positions.[40] Increased values of seated DBP and mean arterial pressure improved at clinical discharge, whereas increased seated HR in female athletes did not. Some changes in autonomic function appear to persist beyond clinical clearance to RTS.[40]

Balance and postural control

Twenty-six studies evaluated a wide range of balance and gait tests to assess SRC within the subacute phase (3–30 days), including: modified Balance Error Scoring System (mBESS) (n=1; 35 participants), Tandem Gait (n=3; 213 participants), Dual Task (n=11; 922 participants), gait temporal-distance parameters (eg, centre of mass; n=5; 136 participants), Concussion Balance Test (COBALT (n=1; 238 participants)) or other postural stability assessments (n=5; 391 participants).

Modified Balance Error Scoring System

The mBESS (ie, floor condition only) is a clinical test of static balance included within successive iterations of the SCAT. Errors have been observed on the single and tandem stances, with 4 errors on the total mBESS reported as the ideal cut point to distinguish concussed from non-concussed athletes (sensitivity=55%, specificity=75%).[42] In comparing mBESS measures in cases of SRC occurring ≤7 days with those >7 days, the AUC was similar (0.69 vs 0.71). The mBESS component of the SCAT3 has shown a small effect size until day 8 post-SRC.[43] Foam conditions of the full BESS provided better discrimination between concussed and control participants during cognitive dual tasks when assessed using measures of postural sway.[44] The magnitude of postural sway also increased in concussed athletes (within 14 days of SRC) versus non-concussed controls with and without the addition of a dual (cognitive) task.[45]

Tandem and dual-task gait

Nine studies (913 participants) assessed the effect of SRC on outcome measures associated with tandem and dual-task gait (simultaneous cognitive and motor tasks). In studies conducted between 3 and 60 days postconcussion, significant differences between concussed and control adolescent and collegiate athletes have been reported with respect to increased postural sway,[46 47] slower gait speed (tandem gait and dual task gait),[47–53] slower cadence,[47 48] shorter stride length[48–50] and worse cognitive accuracy.[50 52] Using a definition of diplopia >5 cm during NPC as abnormal, those with such NPC findings demonstrated slower walking speed than healthy controls 4–10 days postconcussion.[53]

Other

Additional assessments of dynamic postural stability that have demonstrated value in assessing subtle sensorimotor impairments following SRC (mean time from injury 11.4 days) include the Biodex Sway System with an ideal cut point of 1.37 (sensitivity=37%, specificity=88%),[42] The Sensory Organisation Test,[54] and the Multiple Hop Test.[55] Individual components of complex tandem gait outperformed overall composites, specifically, walking forward eyes open (specificity=99%) and walking backward eyes closed (sensitivity=81%).[42] In most studies, balance and gait assessments demonstrated worse distributions in concussed compared with non-concussed athletes. However, results were imprecise and heterogeneous, with no evidence supporting the superiority of a specific test. There were no consistent differences apparent between single-task and dual-task balance and gait assessments, or across patient subgroups defined by age or sex.

Depression and anxiety

Three studies (466 participants) assessed psychological factors within the defined subacute phase following SRC. At baseline (preseason), depression and anxiety were associated with higher symptom scores but were not associated with a worse postconcussion clinical outcome.[56] Significant increases in depressive symptoms have been reported at 1-month postinjury,[56] but not at 1 week.[57 58]

Exercise stress tests

Three studies (629 participants) assessed the effect of exercise in provoking SRC-related symptoms.[38 59 60] Chizuk investigated sex differences in the Buffalo Concussion Treadmill Test (BCTT) in adolescents within 10 days of an SRC.[59] Rate of increase in HR was significantly different between sexes, with female athletes having greater rate of mean HR rise than male athletes. Male athletes reached symptom exacerbation at a lower HR than female athletes. The Buffalo Concussion Bike Test (BCBT) has been shown to be comparable to the BCTT for populations in whom a treadmill test is not feasible.[60]

Multimodal assessments

Combinations of multiple tests in evaluating SRC in the subacute stage were described in 5 studies (2577 participants).[43 61–64] Using a battery of tests that included the PCSS, ImPACT, VOMS and BESS, Sherry found that the total symptom inventory score (p=0.003) and vestibular/oculomotor symptom provocation (p<0.01) were the most sensitive and specific measures, accurately classifying 84.6% of the sample, in a comprehensive, multimodal assessment for distinguishing athletes with SRC from healthy controls within 10 days of injury.[62]

In a study in adolescent ice hockey players using a cervical flexor endurance test, Schneider found that cervical spine measures were significantly worse following concussion compared with preinjury.[63] However, dynamic visual acuity, computerised dynamic visual acuity, head thrust test and functional gait assessment were not different from baseline. Walk-while-talk test scores for divided attention were improved following concussion.

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Leddy *et al* described a focused, brief physical exam consisting of specific cervical, oculomotor and vestibular tests 1–10 days postinjury that discriminated between adolescents with an acute concussion and healthy controls (p=0.0001).[64] The specific elements were: oculomotor (NPC, smooth pursuits, horizontal saccades), cervical spine/occipital nerve (ROM, occipital and cervical tenderness, muscle spasm) and vestibular (VOR, tandem stance, tandem gait with eyes open and closed) with the BCTT added, if needed, to confirm the diagnosis of SRC using symptom provocation.

Of the multiple components of the SCAT3, the symptom checklist has shown the largest group differences and effect size (d=1.52, p<0.001) at 24 hours.[43] At day 8, the differences reduced, but were still significant (d=0.39, p=0.003). There was no significant difference at days 15 and 45 (p=0.458 and p=0.162). Differences between groups were significant at day 8 for the mBESS (d=0.33, p=0.011) but this small effect size was not evident at day 15.

Paediatric-specific

Thirty-six articles included patients in the paediatric age range: 0 papers exclusively 5–12 years of age (children), 13 papers exclusively 13–18 years of age (adolescents), 10 papers included 5–12 and 13–18 years of age, 11 papers included 13–18 years of age as well as adult patients >18 years, and 2 papers included patients 5–12, 13–18 and >18 years of age. Of the papers that included multiple age ranges, only one stratified results by age group.[65] One study was rated high quality, 26 were rated acceptable and 11 were rated as inadmissible through the ROB assessment (online supplemental table 9).

A number of different assessment tools have been used to diagnose SRC in paediatric age groups, including symptom scales (14 studies), cognitive assessments (19 studies), balance tests (9 studies), oculomotor and vestibular tests (6 studies), and physical examination (PE) tests (1 study).

Symptom scales significantly differentiated athletes with SRC versus controls within 10 days of injury.[62 66] Symptom scales showed increased total symptoms and increased symptom severity in concussed athletes in the subacute assessment period (3–30 days postinjury) compared with baseline and healthy controls.[19 24 67 68] Specific symptoms such as dizziness, light sensitivity and feeling slowed down were more severe in concussed athletes than controls.[65] The most commonly used symptom scale was the PCSS,[4] while the Child SCAT incorporated the Health and Behaviour Inventory.[3]

Cognitive tests included CNTs, SAC and single task (standing) and dual task (walking) with cognitive tests. ImPACT was the most commonly used CNT. CNT showed significant differences between concussed athletes and healthy controls in the subacute period,[27] with concussed athletes having impaired verbal memory, visual memory, visual motor speed and motor processing speed 7 days after injury, which persisted up to 14 days in some adolescent athletes.[24 30 69] Lower cognitive task accuracy rates compared with controls have been found during backward spelling and reverse month recitation tasks while walking but similar levels of accuracy while standing.[51]

Balance assessments included BESS, mBESS and tandem gait. BESS scores did not show significant differences between concussed athletes and controls beyond 2 days after injury.[44 62] Balance measures using mBESS have been shown to be significantly different between concussed adolescent athletes and controls in the subacute period with more errors for single leg stance and tandem stance, as well as more total errors in concussed athletes.[42] The ideal cut-point for total mBESS errors to distinguish between concussed and non-concussed athletes is 4 (sensitivity 55%, specificity 75%).[42] Another study showed significant differences only with the tandem stance component in concussed athletes at day 4 postinjury compared with preinjury.[70] Concussed adolescent athletes had significantly more sway/errors than controls an average of 11 days postinjury with complex tandem gait assessments and the ideal cut-point for total number of sway/errors for complex tandem gait was 5 (sensitivity 41%, specificity 90%).[42] The component of tandem gait with the greatest sensitivity was backward eyes closed (81%); the component with the greatest specificity was forward eyes open (99%).[42] Concussed athletes performed tandem gait test slower than controls for both single-task and dual-task conditions and demonstrated worse dual-task cognitive accuracy.[49 50] For the single-task tandem gait test, a cut-point of 16 secs provided 87.5% sensitivity and 72.4% specificity and correctly classified 82.4% of patients as concussed or control. For the dual-task tandem gait test, a cut-point of 22 secs provided 84.8% sensitivity and 72.4% specificity and correctly classified 80.6% of patients as concussed or control.[49]

Oculomotor and vestibular assessments included VOMS. Each component of the VOMS has been shown to be significantly different in concussed adolescents compared with their preinjury scores (tested preseason and then 1–14 days postinjury)[34] or against healthy controls (tested within 10 days of injury).[66 71] Prevalence of vestibulo-ocular dysfunction increased from 38.9% to 72.2% between days 3 and 5 postinjury.[66] Symptom provocation on VOMS significantly predicted athletes with SRC versus controls within 10 days of injury.[31 62] In one study, 61% of concussed athletes reported symptom provocation after at least one VOMS item.[31] VOR and VMS were most predictive of being concussed.[31] NPC distance of ≥5 cm and any VOMS item symptom score ≥2 increased the probability of correctly identifying concussed patients (38% and 50%, respectively).[31] Optimal change score cut-offs were ≥1 for VOMS items and ≥3 for overall VOMS change score. The optimal cut-off for NPC distance was ≥3 cm.[33]

PE, including cervical, vestibular and oculomotor assessments, indicated that abnormal PE signs were significantly greater in concussed athletes compared with healthy controls 1–10 days postinjury. Eighty per cent of concussed athletes had at least one PE abnormal finding.[64]

The use of technology

Nine studies assessed emerging technologies with potential use in an office setting, while acknowledging that such technology may be inaccessible to many HCPs. When comparing symptom scores, BESS and ANAM computerised neurocognitive findings to electroencephalography (EEG) in high school and college athletes, Barr *et al* found there were significant abnormalities on EEG at the time of injury and evidence of persistence for at least 8 days after SRC, with the abnormalities in brain electrical activity persisting beyond athletes' clinical, postural and cognitive recovery.[72] A study using quantitative EEG in concussed athletes showed more significant changes at day 8 than immediately postinjury when compared with baseline measures.[73]

Motor Cognitive Test battery, a computer-based reaction time battery of tests[74]; an i-Pad based Perception-Action Coupling Task,[69] a deep learning network that uses convolutional layers in extracting information from single-trial EEG; event-related potential—the TRauma ODdball Net[75]; and a virtual reality device based on Wii Balance Board technology have all been

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shown to distinguish between concussed athletes and non-concussed controls in the subacute postconcussion period.[76] Athletes tested at baseline, 36 hours postinjury, 4–6 days post-injury and during the postseason demonstrated impaired reaction times at the first postconcussion time point on subtasks with increasing cognitive demands.[74]

A study assessing Brain Network Activation calculated from EEG data related to auditory oddball and go-no-go tasks was unable to differentiate between concussed and control groups.[77]

Differences in oculomotor, vestibular function and reaction time using pupillometry and eye tracking technology have been shown between adolescents/adults with SRC versus controls in the subacute period (mean 5.7 days).[78]

DISCUSSION

This systematic review was framed by two questions:

- ► What additional assessment elements should be added to the SCAT6 for use as an office-based follow-up tool?
- ► Are there any new or emerging technologies to assist in the office-based assessment?

The SCAT is one of the most widely used assessment instruments for evaluating suspected SRC in the acute time period. A range of studies have documented the utility of the SCAT during the acute phase of SRC but the 'signal' from the injury appears to diminish beyond 3 days and can no longer be reliably detected.[10] In addition, there are components of the SCAT, such as the on-field assessment, that are not applicable in an office setting. More specifically, the SAC and mBESS have shown to be poor in discriminating SRC after 3 days.[11] Several reasons may contribute to this lack of diagnostic accuracy beyond the acute period, including:

1. Problems with the tests: the tests themselves may be limited by ceiling effects, test–retest reliability and other psychometric issues (eg, lack of composite scale scores).
2. Characteristics of the injury: the clinical manifestations of SRC are known to be generally time limited, with resolution occurring relatively quickly over time with no or a very weak signal to track. The pathophysiology of the injury is dynamic, creating a 'moving target' that requires distinct tools at different times during the postinjury phase.
3. Imprecise diagnosis: SRC is a non-specific diagnosis with heterogeneous presentation of signs and symptoms and a variety of clinical findings.

In considering the evolution of the SCAT into an office tool more suited to a subacute setting (for the purposes of this review defined as 72 hours to 30 days postinjury), we acknowledge that the literature to date is highly variable in nature with respect to the outcomes evaluated, the timpoint postinjury, age group, level of sport and quality of study design. Future studies evaluating the diagnostic accuracy of tests to (1) differentiate SRC from controls in the subacute time period and (2) differentially diagnose specific systems that may benefit from interventions are needed. The SCOAT6 is an initial office assessment tool to be used by clinicians evaluating athletes/patients with concussion. Thereafter, further evaluation to understand the psychometric properties of the SCOAT6 across timepoints of recovery will facilitate its validation as a multimodal tool. In reviewing studies informing the SCOAT6, the period defined for the included papers was 3–30 days. HCPs may choose to use the SCOAT6 beyond this time frame but should be aware of the parameters of this review.

An office tool, suited to the consultation room environment, provides greater scope for more in-depth and serial assessments, focusing on the clinical features most prominent in the individual athlete. However, as much as the process should be comprehensive, it should also be pragmatic and implementable in a reasonable time frame.

Because of the heterogeneity of clinical presentations following SRC, it is important to develop objective tools that identify manifestations that likely reflect the disruption of physiological function thought to be related to concussion.[79] The content of the tool should also be such that it can be used in different healthcare settings and by HCPs whose primary focus may not be SRC (eg, family practitioners, paediatricians, emergency medicine specialists, physiotherapists) and whose consultation time is limited.

Limitations

The systematic review has limitations that warrant acknowledgement. The studies included in this review are heterogeneous with a wide variation of time frames after SRC (from 3 to 30 days and beyond), ages and sexes. Across studies, there were common challenges with respect to threats to the internal validity of the studies. Included studies used different outcome definitions and often did not report constituents of composite outcomes separately, making interpretation of pooled diagnostic accuracy challenging. Many studies did not blind assessors to case status (ie, SRC vs control) and thus may be subject to measurement bias resulting in overestimate in the difference between groups. Some studies did not report on differences between those who participated in the study versus those who were approached to participate but did not, resulting in potential selection bias. Most of the included studies used prevalence cohorts (ie, groups presenting to a clinic) rather than incidence cohorts (following a group of athletes forward over time to capture all SRC). Thus, the samples likely represent individuals with SRC who may be more severe than if an incident cohort were included, and therefore, may overestimate the differences in test outcomes between SRC and controls. In some studies, analyses did not include consideration of important covariables (eg, previous SRC, migraine headaches, depression, anxiety) that may confound or modify the utility of the tests in differentiating SRC from controls. In addition, many studies included uninjured controls rather than orthopaedically injured controls that would have better controlled for non-specific injury events. There is a dearth of information on children under 12 years of age, sex-specific stratification (including the needs of transgender athletes), and data from under-resourced communities, while the assessment of the para athlete who suffers concussion also remains an area that is also significantly under-researched.

Aspects recommended for inclusion in the SCOAT6 by the expert panel

Following consideration of a systematic review of the available literature (including consideration of ROB) by the expert panel, the following domains are recommended for inclusion in an office-based tool for assessment of SRC. Detailed descriptions of all recommended tests are included in the SCOAT6 (online supplemental file 1)[80]

Symptoms

Symptoms of SRC are the most consistently utilised component of the SRC assessment to both diagnose concussion and monitor recovery. The number and severity of the symptoms has consistently been shown to be a predictor of recovery in adults and adolescents. As part of the medical history, symptoms at the

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time of the consultation should be recorded and, where possible, compared with those documented at the time of injury. To facilitate this comparison, the SCOAT symptom checklist should mirror that of the SCAT6. Similarly, in children, the symptom checklist should be congruent with the Child SCAT6. Additional clinical items such as those described by Davis in the Melbourne Paediatric Concussion Scale warrant inclusion as they may only manifest in the subacute stage of SRC, may help monitor clinical recovery, and further guide management.[81]

Differentiating symptom domains may assist in guiding individualised interventions. Clinicians should be aware that some of the symptoms endorsed may have been pre-existing, coexisting or arising as a reaction to the aftermath of the SRC rather than directly from the SRC itself and a differential diagnosis should be borne in mind, as the symptoms are often non-specific. Also, the broad overlap of symptoms after an SRC can make identifying specific domains challenging, as more than one domain may be involved.[82]

Autonomic nervous system

The autonomic nervous system (ANS) acts unconsciously and regulates involuntary bodily processes such as HR, BP and breathing. Emerging evidence has associated concussion with changes in the ANS. Postulated mechanisms including trauma to the hypothalamus, limbic cortex and midbrain nuclei, regions of the brain responsible for autonomic function.[83] Orthostatic tachycardia has been described as being associated with a substantial subset of concussion clinic patients.[84] Significant orthostatic changes associated with a range of conditions including concussion have been defined as a symptomatic HR increase of at least 30 beats per minute (bpm) in adults and 40 bpm in adolescents when transitioning from supine to standing or tilt test (in the absence of postural hypotension).[85 86] There is some evidence that both BP and HRV changes in response to changes in posture may be affected by concussion but few good quality studies exist in SRC. Assessment of BP and HR form part of a routine medical examination and the office consultation provides an opportunity to record these in the athlete's resting state; measuring both with changes in posture from a supine to upright position while recording symptoms may provide additional clinical information but requires further research.

Cervical spine and neurological examinations

Examination of the cervical spine helps evaluate cervicogenic pain and concussion-related neck injury and should form an integral part of the evaluation of any suspected head injury. Emerging evidence in an incident cohort suggests that the cervical spine may be affected following SRC and should also be assessed in the office setting.[63]

Systematic evaluation of the cranial nerves, motor function (muscle bulk, tone and strength), sensation and deep tendon reflexes, although possibly insensitive to the subtle signs of concussion, remains essential in excluding structural brain injury in the context of contact, collision and combat sports.

Balance and gait

Balance as a domain has been incorporated in each iteration of the SCAT and remains an integral part of clinical evaluation of athletes potentially affected by SRC. The BESS, a clinical test battery that includes a modified Romberg's test, remains the most researched and validated tool in the setting of SRC. However, this test only assesses static balance in a standing position and does not evaluate additional constructs of dynamic balance during locomotion.

SRC may affect dynamic balance during locomotion. More recently, gait analysis, either alone or as part of a dual-task (combined physical or cognitive task) assessment, has received attention. Tandem gait is a validated and practical test, with evidence suggesting that dual-task gait increases the sensitivity of SRC diagnosis. Tandem gait (3 m marked with tape) combined with one of the following cognitive tasks: (1) backward spelling of a 5-letter word; (2) serial subtraction by 7 from a 2-digit number or (3) reciting months in reverse, can distinguish between concussed and non-concussed athletes. For children (<12 years), the dual-task consists of: (1) spelling a four-letter word backwards; (2) serial three subtractions or (3) days of the week backwards. Cues should be varied in subsequent visits to decrease the learning effect and normative values for adults can be referenced.[44] For adolescents, clinically relevant cut-offs have been published.[48]

The Functional Gait Assessment, incorporating straight-line gait with an additional physical task, such as head turns and walking over objects, may add further complexity and sensitivity to the evaluation of the athlete post-SRC but requires further evaluation.[87]

Vestibulo-ocular assessments

Both vestibular and ocular functions may be impacted by concussion. The VOMS is a comprehensive screen evaluating symptom provocation that can differentiate SRC versus controls. Symptom provocation with VOR and VMS tests appear to be associated with concussion.[31] The VOMS can be completed in the office setting and has been validated for ages ≥9 years.[88] More recently a modified, shorter four-item version of the VOMS (mVOMS) (including smooth pursuits, horizontal saccades, horizontal VOR, VMS) has been described that has the same diagnostic accuracy (AUC) and applicability as the original VOMS.[89] A version for ages 5–9 years (VOMS-Child (VOMS-C)) has recently been described but only undergone preliminary evaluation.[90] It is recommended that the mVOMS be incorporated as part of the SCOAT for ages ≥9 years. However, while the VOMS has been shown to be a good tool to differentiate SRC versus controls based on symptom reproduction with testing or NPC distance, it is important to recognise that if symptoms are reproduced during the VOMS this does not 'rule in' the presence of a vestibular or oculomotor problem. Clinical test performance on specific tests to evaluate various functions of the visual and vestibular systems, including differential diagnosis of different types of visual and vestibular problems, is warranted.

Oculomotor function

Eye movements can involve higher cortical function and diffuse pathways.[91] Ocular assessments include a variety of tests including evaluations of pupillary dynamics, and complex cognitive function involving visual-motor coordination and attention. Changes in vision may be reflective of effects on these integrated and diffuse ocular pathways of the brain. NPC testing assessing diplopia at a predetermined cut-off (5 cm from the bridge of the nose) is an easily administered clinical test and could be integrated as part of the broader vestibulo-ocular screen described above. The King Devick test has not been adequately evaluated in the subacute setting. Pupillometry technology has shown potential to distinguish concussed from non-concussed athletes but remains inaccessible to most clinicians and should be regarded as emerging technology.

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Cognitive evaluation

Word recall (immediate and delayed) remains a validated and easily administered form of neurocognitive assessment. Delayed recall should be timed to be at least 5 min after the conclusion of the immediate recall test. Consistent with a ceiling effect found in the use of the 5-word verbal recall test in the SCAT5, a minimum of a 10-word list should be used in the office setting,[6] although it has been suggested that this alone may not be able to distinguish concussed athletes from healthy controls.[92] Lists of up to 15 words may help overcome this but have yet to be validated in SRC.[93]

CNTs, particularly the simple reaction time components, may add additional value as part of an integrated neurocognitive platform. Postinjury CNTs may be compared with an athlete's baseline or community norms. They are not freely available but could form an important part of the office assessment if resources permit.

Mental health aspects

Athletes who present to clinicians' offices, especially those with persisting symptoms, may experience fear, anxiety or depression. These could be as a result of the concussion or be pre-existing or co-existing conditions.[94–96] HCPs have access to several free screening tools, such as the Sport Mental Health Assessment Tool 1, specific to athletes, which may allow for insight into this important aspect of athlete health.[97] Paediatric versions of similar free tools are also accessible.[98] Similar screening instruments and scales are available for sleep dysfunction.[99 100]

Exercise stress tests

Graduated exposure to physical activity in SRC serves several purposes: it potentially provokes symptoms aiding diagnosis, facilitates physiological recovery and forms part of the graduated RTS process. The BCTT and BCBT are validated to provide graduated exercise loads, and to monitor symptoms, perceived exertion and HR response. Where clinical settings have the capability, these should be incorporated in both the assessment and management plan.

Technology use

Technology used to assess SRC included computer-based reaction time batteries, virtual reality balance devices and EEGs, but these forms of technology are not widely available, costly and of uncertain additional benefit to most HCPs.

An area where technology could be used to promote knowledge translation, including more widespread use of the next generation of the SCAT, is to make the tools available in App form that can be accessed online, on tablets and smartphones. Central to this concept is that the tools, including the adult and child versions of the SCOAT6, will be available for free.

Paediatrics

Despite the proliferation of concussion research, relatively few studies focus on paediatric patients, particularly the 5–12 years age group. Many studies that included mixed age groups including adults, adolescents and children did not stratify according to age, and it is unclear if differences in children exist when compared with adolescents or adults. Studies indicate that age is a unique predictor of symptom recovery following concussion,[65] necessitating more research specifically in these younger age groups.

Specific to the Child SCOAT are additional symptom checklists (including symptoms related to concentration and sleep in the subacute period) and differing reference values for orthostatic testing, tandem gait (single and dual task) and the VOMS.

Relevance to the para athlete

In the para athlete, the complexity of the mix of visual, physical and intellectual impairments and their underlying medical diagnoses create a plethora of challenges to the accessibility, implementation, validity and interpretation of clinical testing procedures. A consensus statement by the Concussion in Para Sport Group identifies not only the current guidelines and their limitations but areas requiring further research.[101] Some preliminary work has assessed modifications of the mBESS test for wheelchair users (Wheelchair Error Scoring System (WESS)) in a limited range of type and severity of impairments. A handbook providing guidance based on current knowledge has been produced.[102 103] However, to provide safe and reliable forms of assessment for this diverse population of athletes, all aspects

Key recommendations

Sport-related concussion is a complex injury requiring a multimodal and multiple time point assessment.To facilitate a comprehensive evaluation in the subacute stage, a number of clinical tests should be added to the current Sport Concussion Assessment Tool (SCAT) protocol.

The Sport Concussion Office Assessment Tool 6 (SCOAT6) has evolved from the SCAT6 and aligns with the domains validated since the creation of the SCAT, adding further clinical dimensions.

It is recommended that the following are included in the SCOAT6:

⇒ A 10-word recall and digit backwards test.
⇒ Measurement of systolic and diastolic blood pressure as well as heart rate taken supine after 2 min rest and after standing for 1 min.
⇒ Evaluation of the cervical spine range of motion, muscle spasm, palpation for segmental tenderness and midline tenderness.
⇒ A neurological examination including assessment of cranial and spinal nerves, motor function, sensation and deep tendon reflexes.
⇒ Timed tandem gait as a single task and a more complex dual task with the addition of 3 cognitive tasks (such as serial 7's, months backwards or word recall backwards).
⇒ The modified vestibular ocular motor screening.
⇒ Delayed word recall, a minimum of 5 min after completion of the immediate word recall test.
⇒ A mental health and sleep screen.

For the Child SCOAT6 the following should be added:

⇒ Additional symptoms for child and parent report that capture additional subacute domains.
⇒ An age-appropriate measure of cognitive reaction time such as the Symbol Digit Modalities Test.
⇒ Validated paediatric measures for clinical domains, vestibular-ocular assessment and mental health and sleep questionnaires.

Based on the findings of this multimodal and multiple time point evaluation, the healthcare professional should manage the athlete in an individualised manner, guided by the findings of the SCOAT6 and potentially involving a multidisciplinary team or specialist referral.

With time, the SCOAT6 requires evaluation, validation, refinement and cultural adaptation.

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of the multimodal assessment advocated in the SCOAT6 will require further study in cohorts of para athletes.

Management

Based on the findings of a multimodal and multiple time point evaluation, the HCP should manage the athlete in an individualised manner, guided by the findings of the office assessment and potentially involving a multidisciplinary team or specialist referral. Management may include the prescription of relative cognitive rest, relative physical rest, exercise,[104 105] psychological or neuropsychological assessment and treatment, medication, or vestibular and ocular rehabilitation, or a combination of these interventions. Moreover, based on the SCOAT6, guidance should be given regarding return to learning, work, social activities and sport.

CONCLUSION

A multimodal assessment, including evaluation of signs and symptoms, cognitive function, balance, orthostatic BP and HR, cervical spine, ocular motor and visual function, physical exertion, and psychological and neuropsychological status, is recommended in the subacute time period following SRC. The literature includes heterogeneous studies evaluating a number of tests, at various time points and in different populations following concussion with a lack of consistent recommendations. The SCOAT6 aims to provide a framework to complete a multimodal evaluation in a manner that allows a range of HCPs to use their expertise in the care of athletes who have suffered an SRC, acknowledging variances in resources, SRC-related knowledge and time availability. Further research is required to evaluate the psychometric properties of the SCOAT6 in whole and in part, and to inform adaptations to the SCOAT6 specific to the child athlete and the para athlete.

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She serves as a Team Physician for US Soccer, has received funding for concussion research (NCAA-CARE-DoD 2.0, ended 2020), has received honoraria and reimbursement for travel for speaking and conferences, has written chapters for UpToDate, received royalties for the Netter's Sports Medicine textbook and has provided work as an expert for cases involving concusports medicine topics. GMS is an owner of a multidisciplinary practice (managinsion, team physician and other sg patients with MSKpain disorders).He is a board member of Hockey Calgary (Calgary, AB, Canada) and Chair of the Alberta Association of Physiotherapy. He received funding for the administrative aspects of the writing of two of the systematic reviews that informed the consensus process. KJS has received grant funding from the Canadian Institutes of Health Research, National Football League Scientific Advisory Board, International Olympic Committee Medical and Scientific Research Fund, World Rugby, Mitacs Accelerate, University of Calgary) with funds paid to her institution and not to her personally. She is an Associate Editor of BJSM (unpaid) and has received travel and accommodation support for meetings where she has presented. She is coordinating the writing of the systematic reviews that will inform the 6th International Consensus on Concussion in Sport, for which she has received an educational grant to assist with the administrative costs associated with the writing of the reviews. She is a member of the AFL Concussion Scientific Committee (unpaid position) and Brain Canada (unpaid positions). She works as a physiotherapy consultant and treats athletes of all levels of sport from grass roots to professional. MT is employed full-time as the CEO and Medical Director of ICHIRF—a paid post he has held since April 2015. Hon Medical Adviser to the Professional Riders Insurance Scheme (PRIS)—discretionary honorarium Member of the Premier League Head Injury Advisory Group (HIAG)—no remuneration Director of ICHIRF Ireland—no remuneration Honorary Medical Adviser to the Concussion Foundation—no remuneration Member of the expert panel for the Dept of Digital, Culture, Media and Sport review into concussion in amateur sport—no remuneration Attendance at conferences or meetings as a guest speaker—reimbursement of travel expenses, complimentary registration and payment of hotel accommodation and meals by the organising committee No stocks or options in any concussion-related company No consultancies, board or editorial positions related to concussion. JvI is the founder of R2P Concussion Management. 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Observational Study Monitoring Board (OSMB), Approaches and Decisions in Acute Pediatric TBI (ADAPT) Trial, National Institute of Neurological Disorders and Stroke National Research Advisory Council, National Pediatric Rehabilitation Resource Center, Center for Pediatric Rehabilitation: Growing Research, Education, and Sharing Science (C-PROGRESS), Virginia Tech University.

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