

# What tests and measures should be added to the SCAT3 and related tests to improve their reliability, sensitivity and/or specificity in sideline concussion diagnosis? A systematic review

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## ABSTRACT

**Objectives** Several iterations of the Sport Concussion Assessment Tool (SCAT) have been published over the past 16 years. Our goal was to systematically review the literature related to the SCAT and provide recommendations for improving the tool. To achieve this goal, five separate but related searches were conducted and presented herein.

**Design** Systematic literature review.

**Data sources** Medline, Embase, PsycINFO, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials, SPORTDiscus and PubMed.

**Eligibility criteria** Original, empirical, peer-reviewed findings published in English and included sports-related concussion (SRC). Review papers, case studies, editorials and conference proceedings/abstracts were excluded. The age range for the ChildSCAT was 5–12 years and for the Adult SCAT was 13 years and above.

**Results** Out of 2961 articles screened, a total of 96 articles were included across the five searches. Searches were not mutually exclusive. The final number of articles included in the qualitative synthesis for each search was 21 on Adult SCAT, 32 on ChildSCAT, 21 on sideline, 8 on video/observation and 14 on oculomotor.

**Summary/conclusions** The SCAT is the most widely accepted and deployable sport concussion assessment and screening tool currently available. There is some degree of support for using the SCAT2/SCAT3 and ChildSCAT3 in the evaluation of SRC, with and without baseline data. The addition of an oculomotor examination seems indicated, although the most valid method for assessing oculomotor function is not clear. Video-observable signs of concussion show promise, but there is insufficient evidence to warrant widespread use at this time.

## INTRODUCTION

The Concussion In Sport Group (CISG) introduced the Sport Concussion Assessment Tool (SCAT)<sup>1</sup> to provide a multifaceted standardised assessment of concussion. The SCAT combined previously separate subcomponents of a clinical evaluation, for example, symptoms (graded symptom checklist), cognitive function (five-word immediate recall/delayed recall), the modified Maddocks questions<sup>2</sup> and neurological screening, in one tool. The SCAT

## What are the findings?

- The Sport Concussion Assessment Tool (SCAT) and ChildSCAT are useful in assessing sports-related concussion (SRC), but their diagnostic utility diminishes after 3–5 days.
- Age, sex and sport influence Adult SCAT and ChildSCAT3 performance.
- Developmental differences exist for ChildSCAT3 subcomponents, suggesting the need to tailor test items based on cognitive maturity.

## How might it impact on clinical practice in the future?

- Video-observable signs of concussion hold promise for early detection of SRC.
- Oculomotor assessment may be a useful addition to the SCAT/ChildSCAT, including near point of convergence.
- Enhancements to the SCAT5 will likely lead to increased diagnostic utility of the tool among children, adolescents and adults.

was revised as an instrument to be used by medical professionals and was renamed to SCAT2.<sup>3</sup> The revision was based on a review of the empirical literature, which added the Glasgow Coma Scale (GCS)<sup>4</sup>, a cognitive test (Standardized Assessment of Concussion, SAC<sup>5,6</sup>) and a measure of balance (modified Balance Error Scoring System, mBESS). The SCAT2 was revised as the SCAT3 in 2013,<sup>8</sup> and a new tool for children (under 13) was developed, the ChildSCAT3. The SCAT3 included physical or objective signs of concussion in addition to loss of consciousness (LOC) and balance problems, added a foam condition to the BESS, and included a 'concussion injury advice' section.<sup>9</sup>

This study presents the results of a systematic review of the scientific literature assessing the utility of the SCAT3 and sets forth recommendations for improving the tool.

## MATERIALS AND METHODS

The search strategies for each of the five searches were reviewed by the panel of authors who are



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content experts in the field, as well as a librarian with expertise in systematic reviews. In order to adequately address the question assigned by the CISG, five different (although necessarily overlapping) searches were conducted: Adult SCAT, ChildSCAT, sideline assessment (including SAC, BESS, tandem gait and autonomic dysfunction), video surveillance/observable signs of concussion and oculomotor assessments.

The databases that we examined for the first four searches were Medline, Embase, PsycINFO, Cochrane Central Register of Controlled Trials (all OVID), CINAHL and SPORTDiscus (EBSCOhost). The fifth search was restricted to PubMed and Embase.

Each search included main search concepts. For each concept, keywords and subject headings were generated and then combined with OR. Concepts were then combined with AND. Keywords were consistent across databases, whereas subject headings were translated to respond to controlled vocabulary for each database. The full Medline search strategy for the first four searches and the PubMed search for the fifth topic area are included in online supplementary table 2. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for each search is included in online supplementary table 3, and the corresponding data extraction tables are presented in online supplementary table 4.

The Adult SCAT search included the main concepts: concussion and SCAT. Inclusion criteria consisted of subjects over age 13, used SCAT or SCAT components, sports-related concussion (SRC), English and peer-reviewed (see online supplementary table 1). Two of the authors (RJE and MP) independently applied the selection criteria, with any discrepancy decided by consensus. Risk of bias (ROB) was determined independently by the same authors using the Qualitative Assessment of Diagnostic Accuracy Studies -2 (QUADAS-2),<sup>10</sup> and the level of evidence was assessed using the Oxford Centre for Evidence-Based Medicine (OCEBM), with any discrepancy decided by consensus (see online supplementary table 4).

The ChildSCAT search included the main concepts: paediatric, concussion and SCAT, as well as component categories (eg, children, mBESS). In addition, other potential sideline measures for managing concussions that were discovered on review of included papers are discussed below under the subheading 'other tools'. Inclusion criteria consisted of subjects under age 13, used SCAT or SCAT components, SRC, English and peer-reviewed studies with original data (exclusive of reviews and opinion pieces). Two of the authors (GAD and WPM) independently applied the selection criteria and discussed to reach consensus where there was any disagreement. ROB was determined independently using the QUADAS-2, and the level of evidence was assessed using the OCEBM criteria, with any discrepancy decided by consensus.

The sideline assessment search included three main concepts: concussion, sideline and assessment. Inclusion criteria consisted of participants older than 13 years of age, SRC, sideline assessment of injury, English and peer-reviewed. Given the large number of hits on the original search, the final searches were limited to 2006 to present, and specifically excluded non-peer-reviewed literature (eg, addresses, conferences, editorials) (see online supplementary table 2). Two of the authors (SPB and KMG) independently applied the selection criteria relative to balance and reaction time, with discrepancy decided by parity. ROB was assessed by the same authors using the Downs and Black scale, and the level of evidence was determined using the OCEBM, with any discrepancy decided by consensus (see online supplementary table 4).

The video surveillance/observation search included two main search concepts: concussion and observation. Inclusion criteria included all ages, SRC, observable concussion signs, English and peer-reviewed (see online supplementary table 3). ROB was determined by a single reviewer (GAD) using the QUADAS-2, and the level of evidence was assessed using the OCEBM.

The fifth search addressed oculomotor assessment, with key concepts: concussion, oculomotor/vestibular and sports. The search was limited to 2000 to present. Inclusion criteria consisted of use of visual tests for sideline assessment, SRC, participants older than 13 years of age, English and peer-reviewed. Two of the authors (JJL and SJS) independently applied the selection criteria relative to oculomotor tests, with discrepancy decided by parity. ROB was assessed by the same authors using the Downs and Black scale, and the level of evidence was determined by the OCEBM criteria, with any discrepancy decided by consensus (see online supplementary table 4).

All reviews complied with the PRISMA guidelines.<sup>11</sup> Formal review protocols were not registered or posted.

## RESULTS

### SCAT: adult data extraction

All versions of the SCAT (SCAT, SCAT2 and SCAT3) were included. The search generated 272 articles (see PRISMA flow diagram) and 23 met the inclusion criteria. Five papers met the strict criteria of using the SCAT in its entirety at baseline and postinjury.<sup>12–16</sup> Of these, two did not report on the specifics of the SCAT but instead used normalisation of the SCAT to baseline in contrast with persistent abnormalities on imaging.<sup>15 16</sup> Given the paucity of studies, the inclusion criteria were modified to add the use of the SCAT or its primary components at baseline OR postinjury, including those providing normative data, or performance postinjury compared with other measures. Because the SAC<sup>17</sup> is central to the SCAT, five studies presenting SAC data were added to the synthesis.

The studies included in the final data extraction (see online supplementary tables 1 and 4) were classified as OCEBM level of evidence 3 (45%) or 4 (55%). With respect to ROB, 32% of the studies had low ROB, 41% had moderate risk and 27% were at high risk.

### Studies demonstrating baseline/normative SCAT2/SCAT3 performance

Several studies<sup>12 18–20</sup> (see online supplementary table 1) demonstrated improvement with age on SCAT performance, with adolescents and teenagers performing better than younger children, and college athletes performing better than high school athletes.<sup>12</sup> Some studies<sup>13 20</sup> did not find sex differences on total SCAT2, SAC or balance, although others found that females significantly outperformed males on total SCAT2<sup>18</sup> and SAC,<sup>12 21</sup> and had significantly better scores on the mBESS than males.<sup>12 18</sup> College students playing collision/limited contact sports scored higher on the SCAT2 than those playing non-contact sports<sup>18</sup>. No significant differences were found in baseline total SCAT2/SCAT3 scores among college athletes with or without histories of concussion<sup>6 7</sup>.

Studies found females reported more symptoms<sup>12 19 20 22</sup> and higher symptom severity rating<sup>12 20</sup> at baseline than males. Higher anxiety and depression screening scores were associated with higher SCAT2 symptom scores in college athletes.<sup>13</sup> College athletes playing non-contact sports endorsed more symptoms at baseline than those playing collision/limited contact sports.<sup>21</sup> In a sample of college students,<sup>22</sup> participants could recall

4/5 of the SAC five-word recall list immediately, with women outperforming men on delayed recall and months backwards components. Chin *et al*<sup>12</sup> found that male athletes diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) had higher symptom scores than those without ADHD, and those with ADHD or Learning Disorders (LD) had poorer BESS performance than those without a diagnosis.

In a study of SCAT3 normative values in Finnish Ice Hockey professional athletes,<sup>23</sup> 60% reported a history of prior concussion. Their most common baseline symptom was neck pain (24%). Delayed recall was found to be the most difficult component of the SAC, with only 24% performing the task perfectly. All athletes completed the double leg stance of mBESS without errors, although performance variability was noted on both tandem stance and single leg stance.

#### Studies using SCAT2/SCAT3 at baseline and postinjury

When compared with controls, concussed athletes had more postconcussion symptoms,<sup>12</sup> which remained significant until day 8 postinjury.<sup>12</sup> The SCAT2/SCAT3 total score<sup>13</sup> and SAC differences were found within 24 hours of injury<sup>12 15</sup> but not by day 8 postinjury.<sup>12</sup> Scores on mBESS/BESS were significantly different acutely<sup>12 13</sup> but not on day 15 postinjury.<sup>12</sup> These studies measured participants at 1, 8, 15 and 45 days postinjury. Studies that track recovery postinjury in a more concentrated manner closer to the time of injury show no SCAT/SAC differences between concussed and non-concussed groups typically within 3–5 days postinjury.<sup>5 9 17 24</sup> One study did not find significant differences on the SAC between control/concussed athletes, but differences did emerge with controls showing significantly greater practice effects than injured athletes on SCAT2 total score and SAC.<sup>13 25</sup> Whereas concussed athletes showed an average decrease in scores of 8.9 on the SCAT2 from time 1 to time 2, controls had an increase in scores (ie, practice effect) of 2.9. On the SAC, injured athletes decreased 0.50 on average, whereas controls increased 1.13 during the same time frame.

Putukian *et al*<sup>13</sup> found that when compared with baseline, a 3.5-point drop in the total SCAT2 score had 96% sensitivity and 81% specificity in detecting concussion for college athletes. When examined using normative data, a cut-off value of 74.5 was associated with 83% sensitivity and 91% specificity for predicting concussion versus control status. Similarly, Chin *et al*<sup>12</sup> compared data using intra-individual (baseline–postinjury) and normative approaches (group norms–individual postinjury) collected from a mixed sample of high school and college athletes. Their findings did not support ‘significant added value’ of baseline testing when compared with using normative data. Zimmer *et al*<sup>21</sup> studied college athletes and reached a similar conclusion in situations where baselines cannot be conducted due to limited resources.

#### Studies using SCAT2/SCAT3 postinjury only

Some studies did not include enough detail regarding when the SCAT2/SCAT3 was performed and whether a baseline measure was performed,<sup>25</sup> or did not report SCAT2/SCAT3 performance after injury.<sup>14</sup>

In studies comparing SCAT2/SCAT3 with other modalities, methodological issues make it difficult to discern meaningful information, especially related to evaluating the SCAT2/SCAT3. A study using the SCAT3, neurocognitive testing and diffusion tensor imaging (DTI) did not find any significant differences between the SCAT2 or ImPACT scores in those with and without a history of concussion, but did see differences

on DTI.<sup>26</sup> Specifically, they found significant increases in fractional anisotropy and axial diffusivity, along with a significant decrease in radial diffusivity in the concussed group compared with the non-concussed group. Another study using the SCAT2, neuropsychological testing and functional MRI found SCAT2 and neuropsychological testing were significantly different from baseline within 48 hours postinjury but normalised by 2 weeks.<sup>13</sup>

#### Studies reporting on the SAC

Five studies provided data for the SAC (see online supplementary tables 1 and 2). Male athletes scored significantly lower than females on total SAC in a large sample of high school athletes.<sup>27</sup> McCrea<sup>5 17</sup> studied high school and collegiate football players and reported significant decreases on all SAC components immediately postinjury when compared with uninjured controls, with scores returning to baseline by 48 hours in another mixed high school/college athlete study.<sup>24</sup> A 60-day total SAC test–retest of  $r=0.55$  was reported in a combined high school/college athlete sample.<sup>28</sup>

#### Additional studies using primarily SCAT symptom scores

Several studies reported that they used the SCAT symptom scale but are not reported in detail here because they provided little specific information on the SCAT.<sup>29–33</sup>

#### ChildSCAT

Although there are no published studies that validated the Child-SCAT3 in its entirety among children ages 5–12 at the community level, components of the tool have been individually explored and compared. The ChildSCAT3 was created for ages 5–12 years, and the SCAT3 for 13 years and over, however this arbitrary categorisation of ages has yet to be empirically validated. ROB for the extracted studies was generally low to moderate using QUADAS-2. The typical OCEBM level of evidence for included studies was 3–4, with most studies being cohort studies and case–control studies. The findings are summarised below by the relevant section of the ChildSCAT.

#### Glasgow Coma Scale

No study has examined the utility of the GCS in the Child-SCAT3. The GCS is included, however, as a reminder to medical personnel to examine the potential for more serious brain injury.

#### Sideline assessment: child Maddocks score

Although normative data are available,<sup>34</sup> no study has examined the reliability and validity of the child Maddocks score, including its ability to discriminate concussed from non-concussed children.

#### Symptom evaluation

The ChildSCAT3 incorporates the child and parent-reported list of symptoms from the Health and Behavior Inventory (HBI), which has not been validated against the SCAT3 symptom checklist (Post Concussion Symptom Scale; PCSS) in children. Normative values between the adult and child checklists were examined in 155 athletes between the ages of 5 and 13 years.<sup>35</sup> Younger children reported more symptoms on the ChildSCAT3 than their older counterparts (10–13 years old), with older female athletes reporting more symptoms than younger female athletes.

The Post-Concussion Symptom Inventory (PCSI) has been examined in children, and age-specific versions have been developed that contain fewer symptoms for younger children (5–7



years).<sup>36</sup> Vomiting and numbness/tingling were not effective at differentiating across age groups on both self-reported PCSI and parental report.<sup>36</sup> Among children aged 5–7 years, there were low endorsement and poor differentiation between injured and uninjured participants for 8 out of 13 symptoms.<sup>36</sup> Thus, an abbreviated symptom scale of five items might be sufficient for assessing concussion in younger athletes. The potential advantage of the PCSI over the HBI has yet to be described in SRC.

### Cognitive assessment

The ChildSCAT3 incorporates a modified version of the SAC (SAC-C) that includes fewer orientation questions, a simpler initial stage for digits backwards, and days of the week in reverse order rather than months of the year. Several studies have shown an effect of age on scores on the cognitive components of the SCAT and ChildSCAT3. Twelve-year-olds had difficulty correctly stating the months of the year in reverse order, adding support to the use of days of the week in reverse order.<sup>37</sup> Preliminary data suggest that many children are unable to report the date or correctly recite four digits backwards at baseline.<sup>34 37</sup> Older age was predictive of a better score on all SAC-C measures.<sup>35</sup> Sex is also associated with SCAT/ChildSCAT3 scores.<sup>19 34 35 38</sup> For example, Schneider *et al*<sup>19</sup> found better performance by females than males for months in reverse order and digits backwards using the SCAT, and Nelson *et al*<sup>35 33</sup> found that female sex was associated with a greater symptom burden with age using the ChildSCAT3. There are scant data assessing potential interactions between age and sex.

### Neck examination

Although no study specifically examined the utility of the neck examination within the ChildSCAT3, the neck examination within a concussion assessment tool reminds the clinician that significant cervical injury may occur in any concussed child and should be appropriately assessed to differentiate between cervicogenic and concussive symptoms.

### Balance examination

Normative data have been reported<sup>35</sup> for the child version of the mBESS, which excludes single leg stance. Variable responses to balance assessment in children have been reported, with differences found by age,<sup>34 35</sup> sex,<sup>34 35</sup> stance<sup>39</sup> and surface (hard vs foam). The ChildSCAT3 also includes tandem gait; however, there are no data reported on the utility of mBESS and tandem gait individually or combined in discriminating concussed from non-concussed children.

### Limitations

Although its intended use is for athletes aged 5–12 years, its utility may change over the age spectrum. Age is significantly related to performance on SCAT/ChildSCAT3, with scores generally improving as athletes age.<sup>19 20 27 34 35 40</sup> Practice effects have been documented in some of the subcomponents of the SCAT/ChildSCAT3.<sup>27 41</sup> Improved scores with increasing age and practice effects make it difficult to interpret changes between baseline and postinjury scores.

### Other tools

Studies employing the King-Devick (KD) test are reviewed later in this document. Some studies suggest that near point of convergence (NPC) may add value to the clinical evaluation of SRC, showing greater NPC distance for concussed athletes compared with controls,<sup>14 42</sup> and correlations between NPC

distance and both symptom burden and neurocognitive test results.<sup>43</sup> However, additional data are needed to establish the diagnostic utility of NPC in SRC.

## Sideline assessments

### Balance and reaction time

A total of 10 articles between 2007 and 2016 met our inclusion/exclusion criteria. Five BESS-only studies investigated the effects of modifying factors on balance outcomes. BESS summary scores, the sum of errors from the six stance and surface conditions were evaluated. One study of collegiate athletes found significant variation in BESS performance across sport,<sup>44</sup> which was primarily driven by differences in athlete height. Two studies showed that participants performed worse (higher total errors) on the BESS at a live sporting event compared with a controlled locker room or clinical setting.<sup>45–47</sup>

Two studies examined the relationship between headache, the most common symptom following concussion, and BESS performance.<sup>48 49</sup> Converging results from both studies indicate neither baseline headache endorsement nor presence of post-traumatic headache was associated with BESS performance, suggesting that balance deficiencies are independent of headache.

Two studies compared novel, computerised systems with BESS. The Tekscan MobileMat had fair to excellent agreement with human raters across the six BESS conditions with good agreement (Interclass Correlation; ICC=0.631) to the overall BESS score.<sup>50</sup> In a second study,<sup>51</sup> the Nintendo Wii Balance Board centre-of-pressure path length had better validity and reliability than the BESS, which suffered from poor inter-rater reliability.

The clinical reaction time (RTclin) test, a modified ruler drop test, was examined in three studies, all with non-concussed healthy young adults. Reaction time (ms), calculated from the distance fallen, was extracted and evaluated. One study found good test–retest reliability (ICCs>0.7) across two testing sessions separated by 1 week.<sup>52</sup> This test–retest interval does not always mimic clinical practice as the time between a baseline assessment and injury is typically much longer. Practice effects (ie, faster responses) for RTclin were noted over a 5-week period, with the most pronounced improvement in reaction time occurring between the first two trials.<sup>47</sup> A third study<sup>53</sup> found no association between exercise and reaction time, although a practice effect was found for both the experimental exercise group and the non-exercising controls. Additionally, females had slower reaction time than males.

### Symptoms, orientation and neurological status

Eleven studies were reviewed relative to symptom presentation, orientation, neurological status and sideline concussion assessment. Individual symptom reports, total symptom reports and severity were evaluated. The relationship between athlete-reported headache and concussion appears to be ambiguous in a group of youth American football athletes who reported a headache following a practice or game session. These athletes also reported increases in other symptoms relative to a baseline assessment, but performance on the SAC remained the same and no concussion diagnosis was made through the clinical examination.<sup>49</sup> Similar findings were reported in young adult athletes with a concussion history who reported higher symptoms following a head impact relative to those without a concussion history,<sup>54</sup> despite no concussion diagnosis. Among concussed athletes, higher postinjury reports of symptoms including headache and poorer performance on mental processing and reaction time measures were tied to baseline levels of headache.<sup>47</sup> Additionally,

the Maddocks questions, a subcomponent of the SCAT, demonstrated an 18% false-positive rate among healthy Australian rules football players, suggesting an increased risk of false-positive findings.<sup>55</sup> Collectively, these studies suggest that symptoms commonly associated with concussion may be sensitive to the injury, but they lack the specificity to be used in isolation from other assessment tools.

### Video and observational approaches to concussion identification

The early detection of observable signs of concussion as well as the diagnosis of concussion can be informed by studies employing video technology. One study<sup>56</sup> reviewed the video of Australian football players and found 'slow to get up' to be highly sensitive but non-specific, whereas 'blank and vacant look' had the highest specificity. Additional signs with high specificity were motor incoordination, impact seizure and rag doll appearance. In rugby players, LOC, seizure, body going limp, and blank or vacant stare were predictive of concussion diagnosis.<sup>57</sup> Two studies<sup>58, 59</sup> examined the video of Australian footballers and found tonic posturing, LOC, clonic movements, righting movements and gait unsteadiness to occur in players diagnosed with concussion.

### Oculomotor assessment on the sideline

Fourteen studies met the inclusion criteria for full review. Thirteen of the 14 studies used the KD test on the sideline immediately or on the day of injury, usually within 30–60 min of injury. One study<sup>60</sup> used a portable saccadometer to measure saccadic reaction time or 'latency' of eye movements in amateur boxers before and after competitive bouts. Nine boxers showed a significant latency distribution alteration. In six cases the median latency was significantly increased, and in two cases it was reduced. The four with the greatest increase in postfight latency experienced more head trauma (assessed by blow tallies and, subjectively, by symptoms), one being deemed concussed. The effects were reversible, with recovery over a few days.

All of the KD studies but one<sup>61</sup> were prospective case-control cohort studies. Studies consistently showed that non-concussed individuals demonstrated a learning effect (faster performance) after an athletic contest when compared with their baseline KD values.<sup>60, 62–66</sup> Concussed individuals, however, took statistically significantly longer to complete the test when compared with their baseline scores.<sup>62, 63, 67–72</sup> The range of increased times (ie, reduced performance) was from 4 s to 19 s, with a median increase of 5–8 s. One study<sup>67</sup> showed return to baseline values 1–2 weeks postconcussion. Four studies using KD<sup>69, 71–74</sup> and one using a saccadometer<sup>60</sup> (two in boxing/Mixed Martial Arts and three rugby studies) showed altered oculomotor function in athletes who had sustained head trauma during the contest but who were not diagnosed with concussion. The studies evaluating the KD test thus far are predominantly case-control studies, and more adequately powered prospective studies are needed to establish its diagnostic accuracy.

### DISCUSSION

The SCAT is the most widely accepted and deployable acute concussion tool currently available. There is support for using the SCAT2/SCAT3 and ChildSCAT3 in the evaluation of SRC. Significant differences on the SCAT were found based on age, sex and sport. SAC and mBESS/BESS performance improved with age, with college-age athletes performing better than younger athletes. Females tend to report more symptoms at

baseline compared with men. A diagnosis of ADHD or LD was related to lower scores on SAC total and mBESS, and higher symptom reporting. Females also tend to perform better on the BESS and mBESS than men. The double leg stance of the mBESS has a significant ceiling effect, but the other stances of the mBESS and the BESS demonstrate baseline differences by age and sex.

The data reveal that symptoms, SAC and BESS/mBESS are useful immediately postinjury in differentiating concussed from non-concussed athletes. The largest effect sizes occurred within 24 hours of injury across all subcomponents of the SCAT, including symptoms, symptom severity, SAC and the BESS/mBESS. The diagnostic utility of the SCAT and its components appears to decrease significantly after 3–5 days postinjury. Hence, the utility of the SAC and mBESS as tools to measure recovery beyond 5 days has yet to be established. The symptom checklist does demonstrate clinical utility in tracking recovery.

Baseline testing may be useful but is not necessary for interpreting postinjury scores on the SCAT. Studies that examined differences between intra-individual (baseline to postinjury) and normative data postinjury did not find superiority for either approach, suggesting that a normative approach may prove useful in situations where resources are limited. If baseline test data are used, clinicians must strive to replicate the baseline testing conditions and to consider individual player and sport characteristics when comparing a concussed athlete with control or normative data. More normative data are needed for females and for other sports as the predominance of the research is in male athletes and within the sports of American football and ice hockey.

A limiting factor for the SCAT is a clear ceiling effect for adolescents and adults on the SAC, and hence on the SCAT.<sup>5, 6, 12, 13, 15, 17, 18, 20–24, 27, 28</sup> Specifically, ceiling effects are apparent on the immediate recall subcomponent of the SAC. These ceiling effects may significantly limit the utility of the instrument in detecting subtle changes in athletes' cognitive functioning postinjury. Considerations for increasing the difficulty of the task (eg, increasing the number of words per trial) may help better detect deficits in verbal learning and memory.

Developmental differences are apparent in ChildSCAT3 subcomponents, suggesting the need to tailor test items based on cognitive maturity. For example, the months in reverse order should only be performed by children who correctly answer the days in reverse order, and the mBESS should include single leg stance only for children aged 10–12 years.

RTclin assessment is susceptible to practice effects and sex differences, but it appears to be stable following exercise. This technique, however, has not been used empirically to differentiate concussed from non-concussed individuals. Thus, its clinical utility for concussion assessment and diagnosis has not yet been studied. Although gait assessment has been proposed as an alternative to balance assessment, insufficient data are available to validate the utility of gait assessment for SRC evaluation.

The BESS appears to be the most valid, reliable and practical tool for assessing motor/balance deficits following a suspected concussion acutely, although further exploration/development of inexpensive, portable assessment systems is needed.

Initial findings on the use of video-observable signs of concussion are intriguing and hold promise for enhancing the early detection of concussion. However, additional research to improve sensitivity, specificity and predictive values across multiple sports, age groups and levels of play is required. These studies have notable limitations: they reflect one male professional sport with small sample sizes and are performed post hoc, in the researchers' lab, not on the sideline. Signs have varying

levels of sensitivity and do not occur at the same rate, some with very low frequency, which complicates analyses of their predictive value.

Aggregate data suggest that oculomotor functions are altered at the time of, or shortly after, concussion. This appears to be an objective sign of brain injury and strongly suggests the need for an oculomotor screening examination to provide objective physiological evidence of concussion. However, the best method for this is unclear. The KD test appears to be sensitive to the effects of concussion, reliable,<sup>62, 64</sup> and easy to use and interpret. However, it provides a challenge to its universal use, as it is currently available only as a licensed iPad-based product and thus not readily available to the full spectrum of potential users of the SCAT.

### Limitations

Although comprehensive, the systematic reviews included in this paper have limitations.

Notably absent from most of the studies that examined the SCAT is reference to cultural and linguistic factors that may affect test performance. The lack of identifying such studies may be due to limiting the search strategy to English-language populations only. Limiting the reviews to largely peer-reviewed empirical studies may have narrowed the ability to identify novel or emerging uses of the SCAT. Similarly, by restricting the reviews to sports-related injuries, we also may have missed significant studies that employed the SCAT among individuals injured outside of sports. ROB and level of evidence for the video/observation review were assessed only by one author, which may limit the reliability of that review.

### Summary/conclusions

Taken together, these studies underscore the importance and utility of the SCAT and the ChildSCAT in evaluating SRC during the acute stage of the injury. Although effective in differentiating between athletes with SRC and non-injured controls in the acute stage of the injury, the diagnostic utility of the SCAT and ChildSCAT, and their components, appears to diminish 3–5 days postinjury. Age, sex and sport appear to be associated with Adult SCAT and ChildSCAT3 performance, and clear developmental differences exist for ChildSCAT3 subcomponents, suggesting the need to tailor test items based on cognitive maturity. The identification of observable signs of possible concussion holds promise for early detection of SRC but requires further research. Similarly, oculomotor assessment may be a useful addition to the SCAT/ChildSCAT, including NPC, although additional studies are needed to determine the diagnostic utility of NPC in SRC. Limited data exist on the value of adding reaction time assessment (eg, RTclin) and tandem gait to the SCAT.

The studies reviewed herein represent many methodological approaches with varying levels of methodological rigour. The studies were primarily cross-sectional, cohort and case series designs (levels 3 and 4), with many not employing adequate control groups, a prospective design or sampling a broad range of sports or countries. Adequately powered prospective studies that employ a broad spectrum of athletes prior to and following SRC, with appropriate controls, are critically needed in this area. Normative data for males and females, at all developmental levels, across languages and cultures, and across a variety of sports will markedly enhance the clinical utility of these instruments. Lastly, consistent assessment at close intervals postinjury will increase our understanding of recovery from this injury and

more accurately determine the optimum use of the SCAT when evaluating SRC.

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