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

Ruben J Echemendia,[1,2] Steven P Broglio,[3] Gavin A Davis,[4] Kevin M Guskiewicz,[5] K. Alix Hayden,[6] John J Leddy,[7] William P Meehan,[8,9] Margot Putukian,[10] S John Sullivan,[11] Kathryn J Schneider,[12] Paul McCrory[13]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/10.1136/bjsports-2016-097466).

For numbered affiliations see end of article.

Correspondence to
Dr Ruben J Echemendia, University Orthopedic Center Concussion Care Clinic101 Regent Ct. State College, PA 16801, USA; rechemendia@comcast.net

Accepted 6 March 2017
Published Online First 13 March 2017

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.

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.

INTRODUCTION

The Concussion In Sport Group (CISG) introduced the Sport Concussion Assessment Tool (SCAT)[1] 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[2] and neurological screening, in one tool. The SCAT was revised as an instrument to be used by medical professionals and was renamed to SCAT2.[3] The revision was based on a review of the empirical literature, which added the Glasgow Coma Scale (GCS)[)4], a cognitive test (Standardized Assessment of Concussion, SAC[5 6]) and a measure of balance (modified Balance Error Scoring System,[7] mBESS). The SCAT2 was revised as the SCAT3 in 2013,[8] 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.[9]

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

To cite: Echemendia RJ, Broglio SP, Davis GA, *et al*. *Br J Sports Med* 2017;**51**:895–901.

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),[10] 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 parley. 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 parley. 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.[11] 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.[12–16] 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.[15 16] 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[17] 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[12 18–20] (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.[12] Some studies[13 20] did not find sex differences on total SCAT2, SAC or balance, although others found that females significantly outperformed males on total SCAT2[18] and SAC,[12 21] and had significantly better scores on the mBESS than males.[12 18] College students playing collision/limited contact sports scored higher on the SCAT2 than those playing non-contact sports[18]. No significant differences were found in baseline total SCAT2/SCAT3 scores among college athletes with or without histories of concussion[6 7].

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

Echemendia RJ, *et al*. *Br J Sports Med* 2017;**51**:895–901. doi:10.1136/bjsports-2016-097466

4/5 of the SAC five-word recall list immediately, with women outperforming men on delayed recall and months backwards components. Chin *et al*[12] 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 Disorderds (LD) had poorer BESS performance than those without a diagnosis.

In a study of SCAT3 normative values in Finnish Ice Hockey professional athletes,[23] 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,[12] which remained significant until day 8 postinjury.[12] The SCAT2/SCAT3 total score[13] and SAC differences were found within 24 hours of injury[12 15] but not by day 8 postinjury.[12] Scores on mBESS/BESS were significantly different acutely[12 13] but not on day 15 postinjury.[12] 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.[5 9 17 24] 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.[13 25] 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*[13] 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*[12] 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*[21] 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,[25] or did not report SCAT2/SCAT3 performance after injury.[14]

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.[26] 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.[13]

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.[27] McCrea[5 17] 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.[24] A 60-day total SAC test–retest of r=0.55 was reported in a combined high school/college athlete sample.[28]

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.[29–33]

ChildSCAT

Although there are no published studies that validated the ChildSCAT3 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 ChildSCAT3. 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,[34] 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 ConcussionSymptom 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.[35] 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).[36] Vomiting and numbness/tingling were not effective at differentiating across age groups on both self-reported PCSI and parental report.[36] Among children aged 5–7 years, there were low endorsement and poor differentiation between injured and uninjured participants for 8 out of 13 symptoms.[36] 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.[37] Preliminary data suggest that many children are unable to report the date or correctly recite four digits backwards at baseline.[34 37] Older age was predictive of a better score on all SAC-C measures.[35] Sex is also associated with SCAT/ChildSCAT3 scores.[19 34 35 38] For example, Schneider *et al*[19] found better performance by females than males for months in reverse order and digits backwards using the SCAT, and Nelson *et al*[35 33] 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[35] 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,[34 35] sex,[34 35] stance[39] 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.[19 20 27 34 35 40] Practice effects have been documented in some of the subcomponents of the SCAT/ChildSCAT3.[27 41] 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,[14 42] and correlations between NPC distance and both symptom burden and neurocognitive test results.[43] 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,[44] 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.[45–47]

Two studies examined the relationship between headache, the most common symptom following concussion, and BESS performance.[48 49] 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.[50] In a second study,[51] 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.[52] 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[47]. A third study[53] 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.[49] 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,[54] 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.[47] 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.[55] 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[56] 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.[57] Two studies[58 59] 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[60] 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[61] 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.[60 62–66] Concussed individuals, however, took statistically significantly longer to complete the test when compared with their baseline scores.[62 63 67–72] 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[67] showed return to baseline values 1–2 weeks postconcussion. Four studies using KD[69 71–74] and one using a saccadometer[60] (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.[5 6 12 13 15 17 18 20–24 27 28] 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,[62 64] 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.

Author affiliations
[1]Department of Psychology, University of Missouri - Kansas, Kansas City, Missouri, USA
[2]Concussion Care Clinic, University Orthopedic Centre, State College, Pennsylvania, USA
[3]Department of Kinesiology, University of Michigan, Ann Arbor, Michigan, USA
[4]Murdoch Childrens Research Institue & Florey Institute of Neuroscience and Mental Health, Melbourne, Victoria, Australia
[5]Sports Medicine Research Laboratory, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA
[6]Libraries and Cultural Resources Alberta, University of Calgary, Calgary, Canada
[7]Department of Orthopaedics, SUNY Buffalo, Buffalo, New York, USA
[8]Department of Sports Medicine, Children's Hospital Boston, Boston, Massachusetts, USA
[9]Department of Emergency Medicine, Children's Hospital Boston, Boston, Massachusetts, USA
[10]Department of Athletic Medicine, Princeton University, Princeton, New Jersey, USA
[11]School of Physiotherapy, University of Otago, Dunedin, New Zealand
[12]Faculty of Kinesiology, University of Calgary, Calgary, Canada
[13]The Florey Institute of Neuroscience and Mental Health, Heidelberg, Australia

Contributors RJE assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, drafted and critically reviewed the manuscript, and approved the final version of the manuscript. SB and KMG assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. GAD assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. AH performed the literature searches, drafted tables and methodological statements, performed statistical analyses, edited and critically reviewed the manuscript, and approved the final version of the manuscript. JJL assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. WPM assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. MP assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. JS assisted in designing the study, reviewed identified manuscripts and selected those matching inclusion criteria, edited and critically reviewed the manuscript, and approved the final version of the manuscript. KJ S assisted with executing searches, coordinated risk of bias and level of evidence assessments, and coordinated content of the data extraction tables. She edited and critically reviewed and approved the final version of the manuscript. PM assisted in the design of the study. critically reviewed and approved the final manuscript.

Funding SB receives research funding through NIH-NINDS (3R15NS081691-01S1 and 1R15NS081691-01), National Collegiate Athletic Association and USA Medical Research Acquisition Activity (W81XWH-14-2-0151: 14132004). He also is reimbursed for travel expenses for lectures and scientific meetings. GAD is an honorary member of the Australian Football League Concussion Working Group, and has attended meetings organised by sporting organisations including the National Football League (USA), National Rugby League (Australia) and FIFA (Switzerland); however, he has not received any payment, research funding or other monies from these groups other than for travel costs. RJE is a consultant to the National Hockey League, Major League Soccer, US Soccer Federation and Princeton University. He receives financial remuneration for these consulting relationships. He has a clinical practice in sport neuropsychology and serves as an expert (neuropsychology, sport neuropsychology) in medico-legal cases involving traumatic brain injury. RJE at times receives honoraria and reimbursement of expenses to attend professional meetings. KMG is the Founding Director of the Matthew Gfeller Sport-Related TBI Research Center at the University of North Carolina (USA). He is a member of the National Collegiate Athletic Association's Concussion Committee and the US Soccer Federation (unpaid consultant for both). KMG at times receives honoraria and reimbursement of expenses to speak at professional meetings. AH has nothing to disclose. PM is a co-investigator, collaborator or consultant on grants relating to mild TBI funded by several governmental organisations. He is directly employed by the National Health and Medical Research Council of Australia and is based at The Florey Institute of Neuroscience and Mental Health. He is Co-Chair of the Australian Centre for Research into Sports Injury and its Prevention (ACRISP), which is one of the International University Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee (IOC). He is co-chair of the International Concussion in Sport Group. He has a clinical and consulting

practice in general and sports neurology. He receives book royalties from McGraw-Hill and was employed in an editorial capacity by the British Medical Journal Publishing Group from 2001 to 2008. He has been reimbursed by the government, professional scientific bodies and sporting bodies for travel costs related to presenting research on mild TBI and sport-related concussion at meetings, scientific conferences and symposiums. He received consultancy fees in 2010 from Axon Sports (USA) for the development of educational material (which was not renewed) and has received research funding since 2001 from Cogstate Inc. He has not received any research funding, salary or other monies from the Australian Football League, FIFA or the National Football League. The Australian Football League funds research at the Florey Institute under a legal memorandum, and PM does not receive any money from this industry-funded research. PM is a cofounder and shareholder in two biomedical companies (involved in eHealth and compression garment technologies) but does not hold any individual shares in any company related to concussion or brain injury assessment or technology. He did not receive any form of financial support directly related to this manuscript. WPM receives royalties from (1) ABC-Clio publishing for the sale of his books *Kids, Sports, and Concussion: A Guide for Coaches and Parents*, and *Concussions*; (2) Springer International for the book *Head and Neck Injuries in Young Athlete;* and (3) Wolters Kluwer for working as an author for UpToDate. His research is funded, in part, by philanthropic support from the National Hockey League Alumni Association through the Corey C. Griffin Pro-Am Tournament and by a grant from the Football Players Health Study at Harvard University, which is funded by the NFL Players Association. JJL receives grants/research support from National Institutes of Health, The Ralph C. Wilson Foundation, Program for Understanding Childhood Concussion and Stroke, The Robert Rich Family Foundation, and The Buffalo Sabres Foundation. MP is a medical consultant for Major League Soccer and received financial remuneration for this relationship. She has served as a medical expert on medico-legal cases involving sports medicine and traumatic brain injury and received financial remuneration for these. MP also serves on several committees including the US Lacrosse Sports Science and Safety Committee, US Soccer Medical Committee, and the NFL Head, Neck and Spine Committee, and has received reimbursement of expenses to attend these as well as other professional meetings. KJS has received speaking honoraria for presentations at scientific meetings. She is a physiotherapy consultant at Evidence Sport and Spinal Therapy. JS holds an academic appointment in the School of Physiotherapy at the University of Otago (Dunedin, New Zealand). He occasionally receives reimbursement of expenses to attend professional meetings.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1 McCrory P, Johnston K, Meeuwisse W, *et al*. Summary and agreement statement of the second international conference on concussion in sport, Prague 2004. *Phys Sportsmed* 2005;33:196–204.
2 Maddocks DL, Dicker GD, Saling MM. *The assessment of orientation following concussion in* Athletes. *Clin J Sport Med* 1995;5:32–5.
3 McCrory P, Meeuwisse W, Johnston K, *et al*. Consensus statement on concussion in sport: the 3rd international conference on concussion in sport held in Zurich, November 2008. *Br J Sports Med* 2009;43(Suppl 1):i76–84.
4 Drake AI, McDonald EC, Magnus NE, *et al*. Utility of Glasgow Coma scale - Extended in symptom prediction following mild traumatic brain injury. *Brain Inj* 2006;20:469–75.
5 McCrea M, Kelly JP, Randolph C, *et al*. Immediate neurocognitive effects of concussion. *Neurosurgery* 2002;50:1032–2.
6 McCrea M, Kelly JP, Randolph C, *et al*. Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. *J Head Trauma Rehabil* 1998;13:27–35.
7 Guskiewicz KM. Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep* 2003;2:24–30.
8 McCrory P, Meeuwisse WH, Aubry M, *et al*. Consensus statement on concussion in sport: the 4th international conference on concussion in sport held in Zurich, November 2012. *Br J Sports Med* 2013;47:250–8.
9 Guskiewicz KM, Register-Mihalik J, McCrory P, *et al*. Evidence-based approach to revising the SCAT2: introducing the SCAT3. *Br J Sports Med* 2013;47:289–93.
10 Whiting PF, Rutjes AW, Westwood ME, *et al*; QUADAS-2 Group. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011;155:529–36.
11 Moher D, Liberati A, Tetzlaff J, *et al*; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol* 2009;62:1006–12.
12 Chin EY, Nelson LD, Barr WB, *et al*. Reliability and validity of the sport concussion assessment Tool-3 (SCAT3) in high school and collegiate Athletes. *Am J Sports Med* 2016;44:2276–85.
13 Putukian M, Echemendia R, Dettwiler-Danspeckgruber A, *et al*. Prospective clinical assessment using sideline concussion assessment Tool-2 testing in the evaluation of sport-related concussion in college Athletes. *Clin J Sport Med* 2015;25:36–42.
14 Vernau BT, Grady MF, Goodman A, *et al*. Oculomotor and neurocognitive assessment of youth ice hockey players: baseline associations and observations after concussion. *Dev Neuropsychol* 2015;40:7–11.
15 Wang Y, Nelson LD, LaRoche AA, *et al*. Cerebral blood flow alterations in acute sport-related concussion. *J Neurotrauma* 2016;33:1227–36.
16 Dettwiler A, Murugavel M, Putukian M, *et al*. Persistent differences in patterns of brain activation after sports-related concussion: a longitudinal functional magnetic resonance imaging study. *J Neurotrauma* 2014;31:180–8.
17 McCrea M. Standardized mental status testing on the sideline after Sport-Related concussion. *J Athl Train* 2001;36:274–9.
18 Jinguji TM, Bompadre V, Harmon KG, *et al*. Sport concussion assessment Tool-2: baseline values for high school athletes. *Br J Sports Med* 2012;46:365–70.
19 Schneider KJ, Emery CA, Kang J, *et al*. Examining sport concussion assessment tool ratings for male and female youth hockey players with and without a history of concussion. *Br J Sports Med* 2010;44:1112–7.
20 Snyder AR, Bauer RM; Health IMPACTS for Florida Network. A normative study of the sport concussion assessment tool (SCAT2) in children and adolescents. *Clin Neuropsychol* 2014;28:1091–103.
21 Zimmer A, Marcinak J, Hibyan S, *et al*. Normative values of major SCAT2 and SCAT3 components for a college athlete population. *Appl Neuropsychol Adult* 2015;22:132–40.
22 Shehata N, Wiley JP, Richea S, *et al*. Sport concussion assessment tool: baseline values for varsity collision sport athletes. *Br J Sports Med* 2009;43:730–4.
23 Hänninen T, Tuominen M, Parkkari J, *et al*. Sport concussion assessment tool - 3rd edition - normative reference values for professional ice hockey players. *J Sci Med Sport* 2016;19:636–41.
24 McCrea M, Guskiewicz KM, Marshall SW, *et al*. Acute effects and recovery time following concussion in collegiate football players: the NCAA concussion study. *Jama* 2003;290:2556–63.
25 Samadani U, Ritlop R, Reyes M, *et al*. Eye tracking detects disconjugate eye movements associated with structural traumatic brain injury and concussion. *J Neurotrauma* 2015;32:548–56.
26 Sasaki T, Pasternak O, Mayinger M, *et al*. Hockey concussion education project, part 3. white matter microstructure in ice hockey players with a history of concussion: a diffusion tensor imaging study. *J Neurosurg* 2014;120:882–90.
27 Valovich McLeod TC, Bay RC, Lam KC, *et al*. Representative baseline values on the sport concussion assessment tool 2 (SCAT2) in adolescent Athletes vary by gender, grade, and concussion history. *Am J Sports Med* 2012;40:927–33.
28 Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *J Int Neuropsychol Soc* 2001;7:693–702.
29 Black AM, MacPherson AK, Sergio LE. Number of concussions and time to recovery among female and male varsity Athletes 2008-2011. *Clinical Journal of Sport Medicine* 2012;22:308.
30 Echlin PS, Tator CH, Cusimano MD, *et al*. Return to play after an initial or recurrent concussion in a prospective study of physician-observed junior ice hockey concussions: implications for return to play after a concussion. *Neurosurg Focus* 2010;29:E5.
31 Echlin PS, Tator CH, Cusimano MD, *et al*. A prospective study of physician-observed concussions during junior ice hockey: implications for incidence rates. *Neurosurg Focus* 2010;29:E4.
32 Miller JH, Gill C, Kuhn EN, *et al*. Predictors of delayed recovery following pediatric sports-related concussion: a case-control study. *J Neurosurg Pediatr* 2016;17:491–6.
33 Echlin PS, Skopelja EN, Worsley R, *et al*. A prospective study of physician-observed concussion during a varsity university ice hockey season: incidence and neuropsychological changes. part 2 of 4. *Neurosurg Focus* 2012;33:E2–11.
34 Brooks A, McGuine T, Kebisek J, *et al*. Establishing the psychometric properties of the child sport concussion assessment tool (Child SCAT3). *Clinical Journal of Sport Medicine* 2015;25:214.
35 Nelson LD, Loman MM, LaRoche AA, *et al*. Baseline performance and psychometric properties of the child sport concussion assessment tool 3 (Child-SCAT3) in 5- to 13-year-old Athletes. *Clinical Journal of Sport Medicine* 2016:1.
36 Sady MD, Vaughan CG, Gioia GA. Psychometric characteristics of the postconcussion symptom inventory in children and adolescents. *Arch Clin Neuropsychol* 2014;29:348–63.
37 Glaviano NR, Benson S, Goodkin HP, *et al*. Baseline SCAT2 assessment of healthy youth Student-Athletes: preliminary evidence for the use of the Child-SCAT3 in children younger than 13 years. *Clin J Sport Med* 2015;25:373–9.
38 Khanna N, Baumgartner K, LaBella C. Balance error scoring system results in healthy children with no history of concussion. *Clinical Journal of Sport Medicine* 2013;23:138–9.

39 Nelson LD, Loman MM, LaRoche AA, *et al*. Baseline performance and psychometric properties of the child sport concussion assessment tool 3 (Child-SCAT3) in 5- to 13-year-old athletes. *Clin J Sport Med* 2016:1.
40 Hugentobler JA, Gupta R, Slater R, *et al*. Influence of age on postconcussive postural control measures and future implications for assessment. *Clin J Sport Med* 2016;26:510–7.
41 Jennings D, Sells P, Allison J, *et al*. Effects of a season of subconcussive contact on child- SCAT3 scores in 8-12 year-old male athletes. *Int J Sports Phys Ther* 2015;10:667–75.
42 Mucha A, Collins MW, Elbin RJ, *et al*. A brief vestibular/Ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med* 2014;42:2479–86.
43 Pearce KL, Sufrinko A, Lau BC, *et al*. Near point of convergence after a Sport-Related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. *Am J Sports Med* 2015;43:3055–61.
44 Zimmer A, Piecora K, Schuster D, *et al*. Sport and team differences on baseline measures of sport-related concussion. *J Athl Train* 2013;48:659–67.
45 Onate JA, Beck BC, Van Lunen BL. On-field testing environment and balance error scoring system performance during preseason screening of healthy collegiate baseball players. *J Athl Train* 2007;42:446–51.
46 Rahn C, Munkasy BA, Barry Joyner A, *et al*. Sideline performance of the balance error scoring system during a live sporting event. *Clin J Sport Med* 2015;25:248–53.
47 Register-Mihalik J, Guskiewicz KM, Mann JD, *et al*. The effects of headache on clinical measures of neurocognitive function. *Clin J Sport Med* 2007;17:282–8.
48 Register-Mihalik J, Guskiewicz KM, Mann JD, *et al*. The effects of headache on clinical measures of neurocognitive function. *Clin J Sport Med* 2007;17:282–8.
49 Sabin MJ, Van Boxtel BA, Nohren MW, *et al*. Presence of headache does not influence sideline neurostatus or balance in high school football athletes. *Clin J Sport Med* 2011;21:411–5.
50 Caccese JB, Kaminski TW, Computer-Derived C. And Human-Observed scores for the balance error scoring system. *J Sport Rehabil* 2016;25:133–6.
51 Chang JO, Levy SS, Seay SW, *et al*. An alternative to the balance error scoring system: using a low-cost balance board to improve the validity/reliability of sports-related concussion balance testing. *Clin J Sport Med* 2014;24:256–62.
52 Eckner JT, Richardson JK, Kim H, *et al*. Reliability and criterion validity of a novel clinical test of simple and complex reaction time in athletes. *Percept Mot Skills* 2015;120:841–59.
53 Reddy S, Eckner JT, Kutcher JS. Effect of acute exercise on clinically measured reaction time in collegiate Athletes. *Med Sci Sports Exerc* 2014;46:429–34.
54 Mansell JL, Tierney RT, Higgins M, *et al*. Concussive signs and symptoms following head impacts in collegiate athletes. *Brain Inj* 2010;24:1070–4.
55 Hayter C, Meares S, Shores EA. The abbreviated westmead Post-traumatic amnesia scale and pocket concussion recognition tool: data from amateur sports players in live-match conditionsAdult. *Appl Neuropsychol Adult* 2017;24:1–12.
56 Makdissi M, Davis G. The reliability and validity of video analysis for the assessment of the clinical signs of concussion in australian football. *J Sci Med Sport* 2016;19:85911–863.
57 Gardner AJ, Iverson GL, Stanwell P, *et al*. A video analysis of use of the new 'Concussion Interchange Rule' in the National Rugby League. *Int J Sports Med* 2016;37:267–73.
58 McCrory P. Video analysis of the acute clinical manifestations of concussion in Australian rules football - abstract. In *Australian conference of science and medicine in sport, national convention centre, Canberra 7-10 October 1997: abstracts, Bruce A.C.T*: Sports Medicine Australia, 1997:214–5.
59 McCrory PR, Berkovic SF. Video analysis of acute motor and convulsive manifestations in sport-related concussion. *Neurology* 2000;54:1488–91.
60 Pearson BC, Armitage KR, Horner CW, *et al*. Saccadometry: the possible application of latency distribution measurement for monitoring concussion. *Br J Sports Med* 2007;41:610–2.
61 Marinides Z, Galetta KM, Andrews CN, *et al*. Vision testing is additive to the sideline assessment of sports-related concussion. *Neurology* 2015;5:25–34.
62 Galetta KM, Barrett J, Allen M, *et al*. The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters. *Neurology* 2011;76:1456–62.
63 Galetta KM, Morganroth J, Moehringer N, *et al*. Adding vision to concussion testing: a prospective study of sideline testing in youth and collegiate Athletes. *J Neuroophthalmol* 2015;35:235–41.
64 Leong DF, Balcer LJ, Galetta SL, *et al*. The King-Devick test for sideline concussion screening in collegiate football. *J Optom* 2015;8:131–9.
65 Leong DF, Balcer LJ, Galetta SL, *et al*. The King-Devick test as a concussion screening tool administered by sports parents. *J Sports Med Phys Fitness* 2014;54:70–7.
66 Seidman DH, Burlingame J, Yousif LR, *et al*. Evaluation of the King-Devick test as a concussion screening tool in high school football players. *J Neurol Sci* 2015;356:97–101.
67 Figler R, Hirsch J, Kana D, *et al*. Field utilization of the cleveland clinic concussion ipad assessment tool. *Clinical Journal of Sport Medicine* 2013;23:128.
68 Galetta MS, Galetta KM, McCrossin J, *et al*. Saccades and memory: baseline associations of the King-Devick and SCAT2 SAC tests in professional ice hockey players. *J Neurol Sci* 2013;328:28–31.
69 King D, Brughelli M, Hume P, *et al*. Concussions in amateur rugby union identified with the use of a rapid visual screening tool. *J Neurol Sci* 2013;326:59–63.
70 King D, Clark T, Gissane C. Use of a rapid visual screening tool for the assessment of concussion in amateur rugby league: a pilot study. *J Neurol Sci* 2012;320:16–21.
71 King D, Gissane C, Hume PA, *et al*. The King-Devick test was useful in management of concussion in amateur rugby union and rugby league in New Zealand. *J Neurol Sci* 2015;351:58–64.
72 King D, Hume P, Gissane C, *et al*. Use of the King-Devick test for sideline concussion screening in junior rugby league. *J Neurol Sci* 2015;357:75–9.
73 Galetta KM, Brandes LE, Maki K, *et al*. The King-Devick test and sports-related concussion: study of a rapid visual screening tool in a collegiate cohort. *J Neurol Sci* 2011;309:34–9.
74 e-Pediatrics perspectives. *Pediatrics* 2014;134:380–96.