An assessment of current concussion identification and diagnosis methods in sports settings: a systematic review

Ed Daly1†, Alan J. Pearce2†, Emma Finnegan1, Ciara Cooney1, Maria McDonagh1, Gráinne Scully1, Michael McCann3, Rónán Doherty3, Adam White4, Simon Phelan4, Nathan Howarth4 and Lisa Ryan1*

Abstract

Background: Concussion in sport is an ongoing global concern. The head injury assessment (HIA) by the field of play is acknowledged as the first step in recognising and identifying concussion. While previous systematic literature reviews have evaluated the sensitivity of side-line screening tools and assessment protocols, no systematic review has evaluated the research designs and assessments used in a field setting. This systematic review investigated existing screening and diagnostic tools used in research as part of the HIA protocol to identify concussion that are currently used in professional, semi-professional and amateur (club) sports settings.

Methods: A systematic searching of relevant databases was undertaken for peer-reviewed literature between 2015 and 2020.

Results: Twenty-six studies met the inclusion criteria. Studies were of moderate to good quality, reporting a variety of designs. The majority of studies were undertaken in professional/elite environments with medical doctors and allied health practitioners (e.g., physical therapists) involved in 88% of concussion assessments. While gender was reported in 24 of the 26 studies, the majority of participants were male (77%). There was also a variety of concussion assessments (n = 20) with the sports concussion assessment tool (SCAT) used in less than half of the included studies.

Conclusion: The majority of studies investigating concussion HIAs are focused on professional/elite sport. With concussion an issue at all levels of sport, future research should be directed at non-elite sport. Further, for research purposes, the SCAT assessment should also be used more widely to allow for consistency across studies.

Keywords: Concussion, Head injury assessment, Screening tools, Assessment protocols, Sport injury risk, SCAT

Key points

- Head injury assessments are vital as part of the diagnostic pathway for suspected concussion at all levels of sport.
- This systematic review found that in studies between 2015 and 2020, the majority were focused on elite sports and male participants.
- Studies also utilized a disparate array of assessments making comparison difficult.
- Future studies should aim to focus on amateur (club) sports, include more female participants, and as a minimum include the sports concussion assessment tool (SCAT), along with other assessments to allow for consistency across studies.

© The Author(s) 2022. Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated in a credit line to the data.
Background
Despite consensus on the clinical definition of concussion in sport, its immediate and accurate recognition in a clinical setting/pitch-side setting remains a challenge to implement beyond the elite level of sport. Currently, only a licensed medical practitioner is entitled to diagnose a concussion [1]. However, even at the elite level, clinical decision-making is guided on subjective athlete self-report with observation of symptoms and severity [1]. Further, determination of when an athlete is appropriately ready to return to sport is limited also by subjective symptom scores and imperfect clinical and neuropsychological testing [2]. Despite these challenges, the consensus remains a medical decision based on resolution of symptoms, as reported by the athlete, as well as completing the return to sport guideline protocols [1].

It is important to accurately diagnose a concussion and have the athlete complete a full recovery. It is well described that sustaining a concussion increases the likelihood of incurring a subsequent injury of approximately two-fold [3, 4]. While epidemiological studies only describe the risk, observational studies have suggested that increased risk appears to be due to continuing neurological and neuromuscular impairments post-concussion [5–7]. It has been suggested that experiencing numerous concussions, or exposure to repetitive sub-concussive head trauma, could be associated with long-term consequences such as persistent post-concussive symptoms [8] or increasing risk of neurodegenerative disorders such as chronic traumatic encephalopathy, Alzheimer’s disease, Parkinson’s disease and motor neuron disease [9–13].

Given these risks, it is important that athletes suspected of concussion following an impact are assessed and identified via the removal of participants for suspected concussion following an impact are assessed and identified via the removal of participants for expected concussion following an impact are assessed and identified via the removal of participants for further evaluation and, if diagnosed with concussion, consequently engaged in a graduated return to play protocol [1]. At the elite levels of competitions, the use of head injury assessment (HIA) tools, such as the Sports Concussion Assessment Tool (SCAT) have been evolving since the first consensus statement published in 2001 [14]. While these assessment tools do not replace the medical decision, their use certainly assists the medical practitioner with clinical decision making as well as guidance for return to play clinical decisions for athletes post-concussion. Previous systematic literature reviews have evaluated the sensitivity of sideline screening tools and assessment protocols [15–17]. To date no systematic review has evaluated the overall efficacy of these tools and protocols in a field setting. Moreover, it is unknown if HIAs are utilized in non-elite environments, such as amateur club competitions. This systematic review and qualitative analysis aimed to investigate the prevalence and type of current off-field or ‘side-line’ recognition of suspected concussions. The primary objective was to investigate existing screening and diagnostic tools that are used in identifying concussion, or head injury evaluation protocols that are currently used in professional, semi-professional and amateur (club) sports settings.

Methods
Study design
The review protocol was prospectively registered in the PROSPERO database for systematic reviews (protocol ID: CRD42021214339) and complies with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [18]. The review question and inclusion/exclusion criteria and search terms are presented in Table 1.

Identification of evidence
An electronic search was conducted on 01 July 2020. The following electronic databases were queried: PsychInfo (OVID), PubMed, Science Direct, SPORTDiscus (EBSCOhost), Web of Science, and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (EBSCOhost). The search terms included: (sport related concussion OR SRC OR mTBI OR mild traumatic brain injury) AND (diagnosis OR treatment) AND (sport). Articles met inclusion (eligibility criteria) based on the following prior inclusion criteria: (i) participants were involved in professional/elite, semi-professional/sub-elite or amateur (club) sport at the time of injury; (ii) individuals aged 18 years or greater; (iii) concussion diagnosis assessment was administered acutely (here, we define acute as ≤7 days of injury); (iv) peer-reviewed journal articles published since 2015. Articles prior to 2015 would not be reflective of concussion recognition strategies as outlined in the most recent Concussion Consensus Statement (2016). However, part of our a-priori inclusion criteria was modified. For the purpose of this review we allowed for the inclusion of athletes younger than age 18 years (e.g., studies with an age range of 5–23 years). These studies were considered important as a majority of athletes in these included studies were 18 years or older. Studies in which all participants were under 18 years of age were not included. Full detail on the search strategy and inclusion and exclusion criteria are reported in Table 1.

Selection of evidence and data extraction
Following compilation of online search results, record titles and abstracts were screened by four authors (CC,
ED, MMD, AJP), full text articles were reviewed by five authors (CC, ED, MMD, AJP, LR). The reference lists from review articles were assessed for pertinent studies that may have been overlooked. Data extraction was performed independently by two authors (GS and ED) and data reviewed by a third author (CC) for consistency and accuracy. In cases of disagreement at any stage, consultations with other authors (CC, ED, MMD, AJP, LR) were planned and disagreement resolved by joint discussion and consensus. Figure 1 illustrates the literature review process using PRISMA flow chart [18].

### Data synthesis, statistical analyses and assessment of overall quality of evidence

References were managed in EndNote (Clarivate Analytics, Berkeley California, USA), extracted data were collated in Excel 2013. The overall quality of evidence for each outcome was assessed using a modified Downs and Black [19] checklist for measuring study quality by three authors (AP, ED, LR). Higher total scores for this checklist reflect increased study quality and confidence in conclusions, but we used the stratification of poor (<7), moderate (8–15), good (>16) [20]. However, as some questions were not pertinent to this review, a modified form of the checklist was used for a maximum score of 22. Due to the heterogeneity of the studies a meta-analysis could not be performed, and a qualitative analysis of studies was instead conducted.

### Results

#### Study selection

A total of 7679 citations were screened for eligibility, with the full text of 258 articles retrieved for detailed evaluation. Twenty-six studies met the inclusion criteria following full text review. Figure 1 presents the PRISMA

---

**Table 1** PICO-model and medline search strategy in accordance with PRISMA statement

| Primary review question/aim | Inclusion criteria | Intervention | Outcomes | Study design |
|----------------------------|-------------------|--------------|----------|--------------|
| What are the current side-line screening methods used to establish the diagnosis of acute concussion or suspected concussion across sports in an adult population? | Athletes aged 18 years or greater, involved in amateur, semi-professional or professional sport and sustaining a suspected concussive injury. For the purpose of this review, we allowed for the inclusion of athletes younger than 18 years (e.g., studies with an age range of 5–23 years). These studies were considered important as the cohort included were over 18 years of age. | Any side-line* screening assessment used to detect suspected concussion following sports-related head impact event in the acute phase of injury. For this review the acute phase of injury will be defined as minutes after the event up to and including 7 days post event. These will include (but may not be limited to) reported (i). Concussion 2, (ii) mTBI, (iii) Cervical neck injury | Acute concussion diagnosis methods | Published research, retrospective data analysis, cross sectional study design, parallel studies, prospective, observational, systematic reviews where data meeting the PICO can be extracted. Abstracts (with data) will be included initially. Research published from 2015 onwards |
| Population | | | | |
| Intervention | | | | |
| Outcomes | | | | |
| Study design | | | | |

*Side-line is used generally to denote testing away from the immediate sporting environment, for example rink side, track-side, locker room, medical room, touch line and so on. †MeSH terms were exploded to include more specific terms; MeSH terms were translated into the appropriate subject headings for other databases.

Keywords were the same for each database searched.
Characteristics of included studies

Twenty-six studies (Table 2) met the review inclusion criteria and reported interpretable data on side-line assessments for the diagnosis of concussion. Characteristics of the included studies are summarised in Table 2. Studies consisted of prospective (n = 12), pilot (n = 2), cross sectional (n = 2), prospective observational (n = 1), prospective longitudinal (n = 1), cohort (n = 1), observational (n = 1), descriptive (n = 1), prospective cross sectional (n = 1), pilot case study (n = 1), case control (n = 1) study and retrospective (n = 2). Gender was reported in 24 of the 26 studies with a total population of 7127 participants (5449 males and 1678 females). Twenty studies examined
| Author (year)       | Study type | Level of evidence | Assessment                               | Sample size (concussed/ control) | Sex M/F | Mean age (range) years | Sport                                        | Test post-concussion | Score (max 22) |
|---------------------|------------|-------------------|------------------------------------------|----------------------------------|---------|------------------------|----------------------------------------------|----------------------|---------------|
| Broglio et al. [25] | PCS        | III-2             | BESS, SAC, SCAT5, ImPACT, VOMS, BSI-18   | N = 1458 919/539                 | 19.0 (N/A) |                          | NCAA (sport unspecified)                      | 3 times in 72 h (h): 0–1.25 h (side-line), 1.25–24 h (post-event), 24–72 h (clinic) | 17              |
| Buckley et al. [45] | Cohort     | III-2             | GI                                       | N = 84 (42/42) 40/44             | 19.2 (N/A) |                          | NCAA (sport unspecified)                      | 24 h                 | 16            |
| Downey et al. [21]  | PCS        | III-2             | SCAT3                                    | N = 45 (23/22) 19/26             | 20.0 (N/A) |                          | Football, rugby, ice hockey, soccer, lacrosse, basketball, volleyball, field hockey, baseball, wrestling | 3 to 5 days (acute), 3 weeks (post-acute) | 14            |
| Fallon et al. [30]  | PCS        | III-2             | MULES, SCAT3                             | N = 681 (17) 422/259             | 17 (6–37) |                          | Ice hockey, soccer, football                  | Side-line            | 13            |
| Fuller et al. [31]  | Cross Sectional | III-2           | SCAT3                                    | N = 639 (24) All male            | 27.4 (N/A) |                          | Rugby                                        | After game of injury | 14            |
| Fuller et al. [46]  | Pilot      | III-3             | PSCA1                                    | N = 165 All male                 | N/A      |                          | Rugby                                        | Side-line (Time frame not stated)            | 17            |
| Fuller et al. [37]  | PCS        | III-3             | KD                                       | N = 261 All male                 | 27.6 (N/A) |                          | Rugby                                        | 48 h                 | 18            |
| Fuller et al. [38]  | RCS        | III-2             | HIA01/ SCAT3                             | N = 1265 N/A                     | N/A      |                          | Rugby                                        | Side-line            | 16            |
| Galetta et al. [26] | PCS        | III-2             | KD, SAC, TG                              | N = 332 192/140                  | 11.0 (5–23) |                          | Ice hockey, lacrosse                          | Side-line / rink-side (Time frame not stated) | 15            |
| Gardner et al. [39] | Observational | IV               | VA                                       | N = 400 All male                 | N/A      |                          | Rugby league                                  | N/A                  |               |
| Goble et al. [47]   | Cross-Sectional | III-2           | BBT                                      | N = 25 11/14                     | 20.7 (N/A) |                          | College athletes- (unspecified)               | 48 h                 | 9             |
| Graves [28]         | PCS        | III-2             | SOT, BESS                                | N = 15 (15) All male             | 18.9 (N/A) |                          | Football                                      | 1–14 days            | 15            |
| Hänninen et al. [32] | PCS        | III-3             | SCAT3                                    | N = 283 (27) All male            | 27.0 (N/A) |                          | Ice hockey                                    | 24 h                 | 15            |
| Harrold et al. [33] | PCS        | III-3             | KD, SCAT3                                | N = 426 177/249                  | 35.0 (N/A) |                          | Sport, other                                  | N/A                  | 16            |
| Hecimovich et al. [36] | PCS     | III-2             | KD                                       | N = 22 (7/15) All male           | 19.6 (N/A) |                          | Australian football                            | 10–20 min post-game | 14            |
| King et al. [34]    | PCS Observational | III-2          | KD, SCAT3                                | N = 104 (52/52) All male         | 23.7 (N/A) |                          | Rugby                                        | Days 3, 7, 14, and 21 | 15            |
| Leong et al. [48]   | PCS        | III-3             | KD, SCAT2                                | N = 127 (11) 119/8               | 19.5 (N/A) |                          | Football, basketball                           | N/A                  | 17            |
| Marinides et al. [27] | RCS    | III-3             | KD, PCS, SAC, BESS, ImPACT               | N = 221 (30) 150/71              | N/A      |                          | Football, lacrosse, soccer                    | 87 min               | 14            |
| Merritt et al. [49] | PCS        | III-2             | PCSS, ImPACT                             | N = 846 (86) 637/209             | 19.9 (N/A) |                          | Football, basketball, ice hockey, soccer, lacrosse, wrestling, other | 2, 7, and 14 days post-injury | 18            |
baseline to post-concussion testing. The remaining six studies examined post-concussion exclusively. All studies assessed concussion within the acute diagnosis phase (<7 days). A definition of acute concussion diagnosis was defined in the included studies within the first 3 to 5 days post-concussion [21], ≤48 h after concussion for SCAT3 [22], 24–48 h for BESS, SAC testing, subacute measures of neurocognitive impairment (i.e. ImPACT at 5–7 days and 10–14 days post-injury) [23], 24 h [24] and 72 h post-injury [25]. Included studies were conducted between 2015 to 2020 in a range of countries, including the USA, United Kingdom, Finland, Australia, Canada, South Africa and New Zealand.

Test categories
Included studies (Table 2) used a battery of tests in the diagnosis of side-line concussion (i.e. 'side-line' refers to pitch-side, rink side, changing rooms, or an assessment area immediately available that is not a clinical or hospital setting), that fell into three main testing categories (i) cognitive, (ii) observational and (iii) visual. Fifty-six percent of studies employed cognitive tests, 8% observational, a further 8% visual and 28% used a combination of the three test categories. Nineteen studies used one test category, six studies used two test categories and one study reported the use of tests within all three categories.

Cognitive tests were most commonly employed (n = 16) with a combination of cognitive and observational tests used in a further four studies [23, 26–28]. Two studies used a combination of cognitive and visual [29, 30]. Of the 16 studies that recorded the use of cognitive tests, seven studies used one cognitive test, six studies used two cognitive tests and one study used three cognitive tests. Of the studies that recorded the use of observational testing only, one study used one test while the second study used three testing methods. The two studies that used visual tests exclusively, one test method per study were recorded. The remaining seven studies [23, 26–28] used a combination of cognitive and observational test methods, cognitive and visual test methods [29, 30] or all three test categories [25].

Tests and screening methods used
A total of 20 different concussion diagnosis tests employed across all studies, differing in frequency. Tests included King–Devick (KD; 10 studies), Sports Concussion Assessment Tool (SCAT) version 3 (SCAT3; 9

Table 2 (continued)

| Author (year)            | Study type       | Level of evidence | Assessment methods | Sample size (concussed/ control) | Sex M/F | Mean age (range) years | Sport | Test post-concussion | Score (max score) |
|--------------------------|------------------|-------------------|--------------------|----------------------------------|---------|------------------------|-------|---------------------|------------------|
| Molloy et al. [50]       | Descriptive cohort | III-2             | KD, PSCA2, CogSport| N = 176 (19/33) All male         | 23.8    | (N/A)                  | Rugby | 48 h                | 18               |
| Oldham et al. [22]       | Prospective, longitudinal | III-1         | TG, BESS, mBEss   | N = 76 (38/38) All male           | N/A     |                        | NCAA student-athletes | < 48 h    | 16               |
| Putukian et al. [51]     | Prospective cross-sectional | III-1      | SCAT2             | N = 263 (184/79 (85/178)         | 20.3    | (N/A)                  | Football, rugby, volleyball, football, crew | 0.52 ± 1.18 days | 13               |
| Russell-Giller et al. [29]| Pilot             | IV                | KD, VOMS          | N = 71 N/A                       | 14.0    | (N/A)                  | Sports (unspecified), other | 1–5 days    | 17               |
| Seidman et al. [35]      | PCS               | III-3             | KD, SCAT3         | N = 337 (9/328) All male          | 15.0    | (N/A)                  | American Football | 72 h                | 12               |
| Supfrinko et al. [23]    | Case–control      | III-2             | ImPACT, SAC, BESS | N = 125 (125) 85/40              | 16.8    | (N/A)                  | Football, soccer, volleyball, basketball, wrestling, ice hockey, softball | 13               |
| Vartiainen et al. [24]   | PCS               | III-2             | SCAT3, MotCoTe    | N = 16 (9/7) All male             | 23.4    | (N/A)                  | Ice hockey | 36 h                | 15               |

N/A Not available, KD King Devick test, GI Gait Initiation, SOT Sensory Organization, TG Tandem Gait, GT Gait Termination, MULES Mobile Universal Lexicon Evaluation Systems, HIA1 Head Injury Assessment Version 1, PSCA1 Pitch-Side Concussion Assessment Version 1, PSCA2 Pitch-Side Concussion Assessment Version 2, MotCoTe Motor Cognitive Test Battery, VOMS Vestibular/Ocular Motor Screening, SCAT2 Sport Concussion Assessment Tool Version 2, SCAT3 Sport Concussion Assessment Tool Version 3, SCATS Sport Concussion Assessment Tool Version 5, ImPACT Immediate Post-Concussion and Cognitive Testing, SAC standardized assessment of concussion, PCSS Post-Concussion Symptom Scale, VA Video Assessment, BESS Balance Error Scoring System, mBEss modified Balance Error Scoring System, MotCoTe Motor Cognitive Test battery, PCS prospective cohort study, RCS retrospective cohort study
Most significant symptoms
Two studies employing the SCAT3 reported symptom frequency. Fatigue or low energy, along with neck pain [31] and pressure in head, headache and “don’t feel right” [32] were reported as the most common post-injury symptoms. One study [39] observed “slow to get up” a total of 2240 times on 223 different occasions. Signs of “clutching” were reported 212 times during concussion assessment (58.7%). Other concussion diagnosis signs reported within this study included unresponsiveness (n = 52), gait ataxia (n = 102), vacant stare (n = 98), and a post-impact seizure (n = 4). The study by Fuller et al. [38] asserted that self-reported symptoms and observed clinical signs were the strongest predictors of diagnosed concussion, while conversely immediate memory, tandem gait and Maddock’s questions were weak and not significant predictors of concussion.

Test scores and gender
Two of the 26 studies examined comparison of test scores between females and males. Results were significantly different when compared to each other. Both of these studies used SCAT3 as part [33] or all [21] of the testing protocols. It was clear the results were not similar when compared to each other and further investigation is warranted. For example, Downey et al. [21] reported that while using SCAT3, male participants reported significantly more symptoms (p = 0.012), of greater severity (p = 0.025); and performed significantly worse on the SAC compared to females (p = 0.012). While the study by Harrold et al. [33] reported that using SCAT3, women reported more total symptoms (p = 0.001, linear regression, accounting for age) and had higher symptom severity scores (p = 0.006).

Discussion
This systematic literature review is an analysis of current side-line assessments for the diagnosis of concussion in adults participating in professional, semi-professional and amateur sports. A definition of ‘pitch-side’ in this review included side-line, rink side, changing rooms, or an assessment area immediately available that is not a clinical or hospital setting. The focus for this review was from 2015 onwards to align with the most recent consensus statement of concussion in sport (October 2016), as the authors deemed any study carried out prior to that year (2015) would be outdated. The main findings showed studies overall were of moderate to good quality [20] and a variety of cognitive, observational and visual tests were utilised pitch-side by mostly medical and allied health personnel (e.g. physical therapists) to assess acute concussion in adults. However, the review also found that the majority of studies have investigated mostly professional/

Administration of tests
Tests were administered by medical and non-medical personnel. Eighty-eight percent of participants were tested for concussion by doctors, clinicians, orthopaedic support, neurologists, or the assistance of certified athletic trainers or physiotherapists. Twelve percent of studies used team members, trained volunteers or the study research coordinator to conduct side-line concussion testing for scientific purposes only.

Level of sport
A range of different sports and levels of participation were reported in the included studies. For example, sports included rugby (union and league), American Football, ice hockey, baseball, soccer, Australian rules football, basketball, volleyball and wrestling. The sport activities can be divided into two different levels of participation: (1) professional/elite, semi-professional and (2) amateur/club, community level sports. 56% of participants fell into the professional/elite or semi-professional levels of sport, 36% were categorised as amateur/club or community sports. Another 4% were classified as a mixed level cohort of participants who were professional/elite, semi professional and amateur level athletes within a study. The remaining 4% did not state the level of sports played by those participants, however it is important to note the study did not report the level of sports played and testing was carried out within multidisciplinary concussion centres.

studies), Balance Error Scoring System (BESS; 5 studies), Standardised Assessment of Concussion (SAC; 5 studies), tandem gait (TG; 3 studies), immediate post-concussion assessment and cognitive testing (ImPACT; 4 studies), video assessment (VA; 1 study), SCAT version 2 (SCAT2; 2 studies) and vestibular and oculomotor screening (VOMS; 2 studies). The following 11 tests were used once within the range of 16 studies (Brief Symptom Inventory-18, Gait Initiation, Mobile Universal Lexicon Evaluation System, Pitch-Side Concussion Assessment, BTrackS Balance Test, Post-Concussion Symptom Scale, Pitch-Side Concussion Assessment (version 2), CogSport, modified Balance Error Scoring System, Motor Cognitive Test battery, SCAT5). SCAT3 was used on its own in three studies [21, 31, 32]. Three studies used SCAT3 and KD testing in combination with each other [33–35]. Three studies used KD, individually [29, 36, 37]. One study used TG testing along with a combination of cognitive tests [26]. VOMS was used along with a set of cognitive/cognitive and observational tests [25, 29]. One study assessed the diagnostic accuracy of their own developed HIA test which incorporated elements of the SCAT3 [38]
elite or semi-professional cohorts, aligning with these studies likely having access to medical and allied health staff to undertake these assessments. Conversely the limitation in non-medically trained researchers operating assessments is likely to be contributing to the paucity of studies being undertaken at non-elite/club levels of participation where research is urgently required.

Key findings from the qualitative review showed a large range of different assessments used to quantify concussion. Interestingly, we found that less than half of the studies employed the SCAT assessment (either SCAT2, 3 or 5 for this systematic review). We found this observation surprising given that it has been suggested that the SCAT is the most widely accepted and deployable sport concussion assessment and screening tool currently available [15]. We appreciate that the use of SCAT in research is not a mandatory requirement, and that the objective of studies would be to test the efficacy of other modalities and cohorts, such as in a laboratory environment. However, in field studies such as those included in this review, to reduce disparity in findings, the SCAT assessment should be used consistently across future studies.

The review also found that ~25% of studies used a multi-modal approach to assess concussion by combining two or more testing batteries. While it may be argued that the SCAT does incorporate a multi-modal approach [1], there are elements that the SCAT assessment does not measure, such as the oculo-motor system [15]. Indeed, a previous study where the SCAT and an oculo-motor test such as the King–Devick (KD) test have been implemented together, results showed a 100% sensitivity in diagnosing athletes suspected of concussion [40]. For clinically focused studies and application to clinical-practice, future work should incorporate two or more rapid and non-invasive pitch-side assessments for the diagnosis of concussion to reduce the risk of false-positives or false-negative diagnoses occurring, which may affect follow up results. This has been recently suggested in a systematic review by Harris et al. [41].

An ongoing concern, particularly for concussion in non-elite/community club-based sports, is the paucity of suitably qualified people who are allowed to administer the SCAT HIA. This is reflected in the current review where the majority of studies used SCAT at professional/elite levels of sport, where access to a medical practitioner was possible. As the consensus statement strictly asserts that only a medical practitioner can administer the SCAT as part of the clinical diagnosis [1], this may limit opportunities for suitably qualified scientists who are technically proficient at the SCAT but cannot provide a result, limiting research. Conversely other assessments such as the VOMS can be delivered by allied health professionals and the KD can be delivered by anyone, increasing their potential usage in research, but due to aforementioned limitations this would be without the use of the SCAT (despite assertions that the SCAT is the most widely agreed upon assessment tool for concussion) [15]. As studies have argued that when used in isolation assessments such as the KD or VOMS may not be sensitive enough alone to detect concussion [37, 42], we suggest from this systematic review that the SCAT should be incorporated with other testing modalities for data collection purposes, with any clinical diagnosis made by the associated team doctor outside of the study scope.

Interestingly, despite consensus on the use of video identification of concussion [43], only one study in this systematic review utilised video. A reason for this was because the video was used for post-event confirmation rather than used for confirmation of concussion at time of incident. With network media covering professional/elite events, video is easily accessible at matches. However, although multiple and multi-angled cameras are not available at amateur/community club levels, many sub-elite competitions will now incorporate a fixed camera supplied by the clubs themselves or via the local league for streaming or replay on the league’s webpage. While not optimal in terms of clarity, it may assist the detection of concussion and we suggest that future studies involve video to confirm concussion events to improve study quality. Similarly, we found no studies employing impact sensors in a surveillance capacity. The use of impact sensors (attachments behind the ear or embedded within a gumshield/mouth guard) will assist video confirmation of suspected concussion events, however with no studies to support this hypothesis, we conclude no studies using impact sensors were eligible for inclusion in this systematic review.

Limitations of this review include research involving lab-based clinical assessments. However, the focus of this review was on published research that could assist at the lower levels of sport in community or amateur settings (i.e. in settings where the presence of medical professionals’ pitch-side may be limited or indeed non-existent). Another limitation we acknowledge is that the laws of each individual sporting code may not allow for head injury assessments during the game: this may influence timing of assessments and the ability to ‘Recognise and Remove’. In these instances, the general approach would be to remove the participants from the sports activity where there is any indication that a concussion has occurred. These initial sideline tests may be substantiated at a later time using advanced diagnostic techniques by a medical professional or video analysis. The studies included in this review utilised well established testing methods which offered some form of side-line tests for
suspected concussions and have highlighted the necessity for a multimodal concussion assessment tool for the initial identification and assessment of concussion. This review highlighted the need for multi-modality concussion testing and that there is a clear disparity in research focusing on professional/elite levels and the lack of studies in amateur/club levels (Additional files 1, 2).

Conclusions
Recognising suspected concussion in sports participants is most effectively realized by using multimodal test protocols that are guided (via primary or secondary confirmation) by medical experts. Based on this review, the KD and SCAT (versions 2 and 3) appear to be the most commonly used tools for the primary assessment of concussion currently. Using additional tests such as VOMS from an observational perspective and balance testing such as BESS show promise in conjunction with cognitive testing. The addition of concurrent video review could potentially offer a promising approach to improve identification and evaluation of significant head impact events, and a multi-modality-based concussion evaluation process appears to be important to detect delayed-onset SRC, however current evidence does not support the use of impact sensor systems for real-time concussion screening. As shown in a recent systematic review [41] there is an urgent need to conduct research, using multi-modality assessment methods, but focusing on non-elite levels where concussion injuries occur regularly but a lack of resources and education preclude effective assessment and management.

Abbreviations
KD: King Devick test; GI: Gait Initiation; SOT: Sensory Organization; TG: Tandem Gait; GT: Gait Termination; MULES: Mobile Universal Lexicon Evaluation Systems; PSCA: Pitch-Side Concussion Assessment Version 1; PSCA2: Pitch-Side Concussion Assessment Version 2; MotCoTe: Motor Cognitive Test Battery; VOMS: Vestibular/Ocular Motor Screening; SCAT2: Sport Concussion Assessment Tool Version 2; SCAT3: Sport Concussion Assessment Tool Version 3; SCAT5: Sport Concussion Assessment Tool Version 5; IMPACT: Immediate Post-Concussion and Cognitive Testing; SAC: Standardized assessment of concussion; PCS: Post-Concussion Symptom Scale; VA: Video Assessment; BESS: Balance Error Scoring System; mBESS: Modified Balance Error Scoring System; MotCoTe: Motor Cognitive Test battery; PCS: Prospective cohort study; RCS: Retrospective cohort study.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s13102-022-00514-1.

Additional file 1. Categorisation of test type and the tests included in each.

Additional file 2. PRISMA checklist.

References
1. McCrory P, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017;51(11):838–47.
2. Kamins J, et al. What is the physiological time to recovery after concussion? A systematic review. Br J Sports Med. 2017;51(12):935–40.
3. Nordstrom A, Nordstrom P, Ekstrand J. Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players. Br J Sports Med. 2019;47(7):1754–62.
4. McPherson AL, et al. Musculoskeletal injury risk after sport-related concussion: a systematic review and meta-analysis. Am J Sports Med. 2019;47(7):1754–62.
5. Howell DR, et al. Neuromuscular control deficits and the risk of subsequent injury after a concussion: a scoping review. Sports Med. 2018;48(5):1097–115.
6. Wilkerson GB, Grooms DR, Acocella SN. Neuromechanical considerations for postconcussion musculoskeletal injury risk management. Curr Sports Med Rep. 2017;16(6):419–27.
7. Scott E, et al. The neurophysiological responses of concussion impacts: a systematic review and meta-analysis of transcranial magnetic stimulation studies. Front Hum Neurosci. 2020;14:306.

8. Pearce AJ, Tommerdahl M, King DA. Neurophysiological abnormalities in individuals with persistent post-concussion symptoms. Neuroscience. 2019;408:272–81.

9. Livingston G, et al. Dementia prevention, intervention, and care: 2020 report of the Lancet Commission. Lancet. 2020;396(10248):413–46.

10. Mez J, et al. Clinicopathological evaluation of chronic traumatic encephalopathy in players of American football. JAMA. 2017;318(4):360–70.

11. Suter CM, et al. Chronic traumatic encephalopathy in Australia: the first three years of the Australian Sports Brain Bank. Exp Neurol. 2021;40:210–9.

12. Delic V, et al. Biological links between traumatic brain injury and Parkinson’s disease. Acta Neuropathol Commun. 2020;8(1):1–16.

13. Rubenstein R. The link between traumatic brain injury and neurodegenerative diseases. In: Wang K, editor. Neurotrauma: a comprehensive textbook on traumatic brain injury and spinal cord injury. Oxford: Oxford University Press, 2018. p. 165.

14. Aubry M, et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. Br J Sports Med. 2002;36(1):6–10.

15. Echemendia RJ, et al. 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. Br J Sports Med. 2017;51(11):895–901.

16. Swart J, et al. Harrogate consensus agreement cycling specific sport related concussion. Sports Med Health Sci. 2021;3(2):110–4.

17. Patricios J, et al. What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review. Br J Sports Med. 2017;51(11):888–94.

18. Page MJ, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372: n71.

19. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998;52(6):377–84.

20. Jäkel A, von Hauenschild P. Therapeutic effects of cranial osteopathic manipulative medicine: a systematic review. J Am Osteopath Assoc. 2011;111(12):685–93.

21. Donvrey RI, Hutchison MG, Comper P. Determining sensitivity and specificity of the Sport Concussion Assessment Tool 3 (SCAT3) components in university athletes. Brain Inj. 2018;32(1):1345–52.

22. Oldham JR, et al. Efficacy of tandem gait to identify impaired postural control after concussion. Med Sci Sports Exerc. 2018;50(6):1162–8.

23. Patricios J, et al. What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review. Br J Sports Med. 2017;51(11):888–94.

24. Vartinen MV, et al. A novel approach to sports concussion assessment: computerized multilimb reaction times and balance control testing. J Clin Exp Neuropsychol. 2016;38(3):293–307.

25. Broglio SP, et al. Acute sport concussion assessment optimization: a prospective assessment from the CARE Consortium. Sports Med. 2019;49(12):1977–87.

26. Galetta KM, et al. Adding vision to concussion testing: a prospective study of sideline testing in youth and collegiate athletes. J Neuroophthalmol. 2015;35(3):235–41.

27. Marinides Z, et al. Vision testing is additive to the sideline assessment of sports-related concussion. Neurol Clin Pract. 2015;5(1):25–34.

28. Graves BS. University football players, postural stability, and concussions. J Strength Cond Res. 2016;30(2):579–83.

29. Russell-Giller S, et al. Correlating the King–Devick test with vestibular-ocular motor screening in adolescent patients with concussion: a pilot study. Sports Health. 2018;10(4):334–9.

30. Fallon S, et al. MULES on the sidelines: a vision-based assessment tool for sports-related concussion. J Neurol Sci. 2019;402:52–6.

31. Fuller CW, et al. Evaluation of World Rugby’s concussion management process: results from Rugby World Cup 2015. Br J Sports Med. 2017;51(1):64–9.

32. Hanninen T, et al. Sport Concussion Assessment Tool: interpreting day-of-injury scores in professional ice hockey players. J Sci Med Sport. 2018;21(8):794–9.

33. Harold GR, et al. Rapid sideline performance meets outpatient clinic: results from a multidisciplinary concussion center registry. J Neurol Sci. 2017;379:312–7.

34. King D, 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(1–2):58–64.

35. Seidman DH, et al. Evaluation of the King–Devick test as a concussion screening tool in high school football players. J Neurol Sci. 2015;356(1–2):97–101.

36. Hecimovich M, et al. The King–Devick test is a valid and reliable tool for assessing sport-related concussion in Australian football: a prospective cohort study. J Sci Med Sport. 2018;21(10):1004–7.

37. Fuller GW, et al. King–Devick concussion test performs poorly as a screening tool in elite rugby union players: a prospective cohort study of two screening tests versus a clinical reference standard. Br J Sports Med. 2019;53(24):1526–32.

38. Fuller G, et al. The performance of the world rugby head injury assessment screening tool: a diagnostic accuracy study. Sports Med - Open. 2020;6(1):1–12.

39. Gardner AJ, et al. Evidence of concussion signs in National Rugby League match play: a video review and validation study. Sports Med - Open. 2017;3:1–10.

40. Ventura RE, et al. Diagnostic tests for concussion: is vision part of the puzzle? J Neuroophthalmol. 2015;35(1):73–81.

41. Harris SA, et al. Do sideline tests of vestibular and oculomotor function accurately diagnose sports-related concussion in adults? A systematic review and meta-analysis. Am J Sports Med. 2021. https://doi.org/10.1177/03635465211027946.

42. Yorke AM, et al. Validity and reliability of the vestibular/ocular motor screening and associations with common concussion screening tools. Sports Health. 2017;9(2):174–80.

43. Davis GA, et al. International consensus definitions of video signs of concussion in professional sports. Br J Sports Med. 2019;53(20):1264–7.

44. National Health and Medical Research Council. A guide to the development, implementation and evaluation of clinical practice guidelines. Canberra, 1999.

45. Buckley TA, et al. Decreased anticipatory postural adjustments during gait initiation acutely postconcussion. Arch Phys Med Rehabil. 2017;98(10):1962–8.

46. Fuller GW, Kemp SP, Decq P. The International Rugby Board (IRB) Pitch Side Concussion Assessment trial: a pilot test accuracy study. Br J Sports Med. 2015;49(8):529–35.

47. Goble DJ, et al. An initial evaluation of the BITrack balance plate and sports balance software for concussion diagnosis. Int J Sports Phys Ther. 2016;11(2):149.

48. Leong DF, et al. The King–Devick test for sideline concussion screening in collegiate football. J Optom. 2015;8(2):131–9.

49. Merritt VC, Meyer JE, Arnett PA. A novel approach to classifying post-concussion symptoms: the application of a new framework to the Post-Concussion Symptom Scale. J Clin Exp Neuropsychol. 2015;37(7):764–75.

50. Molloy JH, Murphy I, Gissane C. The King–Devick (K–D) test and concussion diagnosis in semi-professional rugby union players. J Sci Med Sport. 2017;20(8):708–11.

51. Putukian M, 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(1):36–42.