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What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion? A systematic review.

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ABSTRACT

Background

Sideline detection is the first and most significant step in recognising a potential concussion and removing an athlete from harm. This systematic review aims to evaluate the critical elements aiding sideline recognition of potential concussions including screening tools, technologies and integrated assessment protocols.

Data Sources

Bibliographic databases, grey literature repositories and relevant websites were searched from 01/01/2000 to 30/09/2016. A total of 3,562 articles were identified.

Study selection

Original research studies evaluating a sideline tool, technology or protocol for sports related concussion were eligible, of which 27 studies were included.

Data extraction

A standardised form was used to record information. The QUADAS-2 and Newcastle-Ottawa tools were used to rate risk of bias. Strength of evidence was assessed using the GRADE system.

Data synthesis

Studies assessing symptoms, the King-Devick test and multi-modal assessments reported high sensitivity and specificity. Evaluations of balance and cognitive tests described lower sensitivity but higher specificity. However, these studies were at high risk of bias and the overall strength of evidence examining sideline screening tools was very low. A strong body of evidence demonstrated that head impact sensors did not provide useful sideline concussion information. Low strength evidence suggested a multimodal, multi-time based concussion evaluation process incorporating video review was important in the recognition of significant head impact events and delayed onset concussion.

Conclusion

In the absence of definitive evidence confirming the diagnostic accuracy of sideline screening tests, consensus derived multimodal assessment tools, such as the Sports Concussion Assessment Tool (SCAT), are recommended. Sideline video review may improve recognition and removal from play of athletes who have sustained significant head impact events. Current evidence does not support the use of impact sensor systems for real-time concussion identification.

INTRODUCTION

Despite a consensus definition of sports-related concussion (SRC) having been well elucidated,[1] its immediate and accurate recognition in a clinical setting remains a challenge.[2] Sustaining a SRC may increase the likelihood of incurring a subsequent head or musculoskeletal injury,[3] and repeated concussions could be associated with long term consequences such as persistent post-concussive symptoms, depression or neurodegenerative disorders.[1 4 5] Early detection of suspected concussion and removal of the affected player will help prevent these potential adverse sequelae and facilitates further evaluation, management and safe return-to-play. This systematic review aims to evaluate the critical elements aiding off-field (commonly termed 'sideline') recognition of potential concussions. Specific objectives were to assess the diagnostic accuracy of existing clinical screening and diagnostic tools, determine the utility of technology in detecting SRC and assess integrated head injury assessment protocols currently used in professional collision sports.

METHODS

Study design

Expert consensus guidelines for the conduct of systematic reviews were followed, [6-8] and a detailed protocol stating an a priori analysis plan was registered before data collection (PROSPERO 2016:CRD42016037831). The review question and inclusion/exclusion criteria are detailed in Table 1. Supplementary details on methodology, including a glossary of technical terms, are presented in the web appendix.

Identification of evidence

An extensive range of electronic information sources were examined including all major bibliographic databases, specialist sports medicine databases, grey literature repositories and relevant websites (see web appendix for details). Additional information sources included forwards and backwards citation searching, author searching, reference checking and contact with experts. Search strategies for bibliographic databases were developed iteratively in conjunction with an information services specialist (University College London) and underwent external peer review (University of Sheffield).

Searches were conducted for original research published between 2000 (corresponding to the modern definition of concussion) and Week 4, April 2016 and were otherwise unrestricted. Current awareness searches were conducted in MEDLINE and Embase (Week 4, September 2016) immediately prior to submission.

Selection of evidence and data extraction

Original research studies identified during searches were assessed in a four stage process by teams of two independent reviewers. Firstly, titles and abstracts were screened for relevance. Secondly, full-text articles were examined as required to assess eligibility. Thirdly, studies meeting review inclusion criteria were classified into domains pertaining to: sideline screening tests (comprising subtopics of clinical signs and symptoms, balance tests, oculomotor assessments, cognitive tests and multi-modal testing strategies); technology; and professional sports-specific head injury assessment protocols (defined in Table 1). Finally, data extraction was performed separately for eligible studies within each sub-topic. A single unblinded reviewer extracted information on study characteristics, methodology and results using a standardised data extraction form; and a second reviewer independently checked data for consistency and accuracy. In cases of disagreement at any stage, consultation with a third author was planned, with consensus derived by arbitration.

Risk of bias assessment

Included studies were assessed for risk of bias using peer reviewed critical appraisal checklists appropriate to study design. The QUDAS-2 tool was used for diagnostic accuracy studies.[9] Observational studies were evaluated using the Newcastle-Ottawa scale.[6] A single un-blinded reviewer within each sub-group team assessed risk of bias, with a second reviewer independently checking the assessment for validity. Any disagreement between reviewers was resolved by consensus and consultation with a third author with expertise in epidemiology and critical appraisal.

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

Data analysis and synthesis was performed separately for eligible studies within each sub-topic. Results are presented descriptively with reported point estimates and 95% confidence intervals and summarised graphically using Forrest Plots.[10] Heterogeneity was assessed using the I^2 statistic.[11] A narrative synthesis was pre-specified in the event that clinically and methodologically homogenous studies at low risk of bias were not identified. References were managed in EndNote (Thomson Reuters, CA, USA), extracted data were collated in Excel 2013 (Microsoft, Redmond, USA), and Forrest Plots were formulated using Meta-DiSc version 1.4 (University of Birmingham, UK). The overall quality of evidence for each outcome was assessed using the consensus Grades of Recommendation, Assessment, Development and Evaluation Working Group (GRADE) approach.[12] GRADE is a systematic method of assessing quality of evidence and strength of recommendations taking into account methodological flaws, consistency of results, generalisability of findings and the effectiveness of treatments. A clinical diagnosis of concussion was the primary outcome for each domain.

Table 1. Review question and inclusion criteria

Primary Review Question/Aim	
What are the critical elements of sideline screening that can be used to establish the diagnosis of concussion or suspected concussion?	
Inclusion Criteria	
Population	Athletes competing in sporting activity and sustaining a non-trivial head impact event [includes: any nationality, gender, age group, or level of performance].
Intervention / index tests	Any sideline* screening assessment used to detect suspected concussion following sports-related significant head impact events [including: historical features, symptoms, physical findings, clinical tests, or technologies]
Outcome / reference standard	Concussion, clinically diagnosed by a registered medical practitioner.
Study design	Published or unpublished studies of any research design.
Exclusion Criteria	
Population	Not related to sport, subjects <13 years, animal studies
Intervention / index tests	Non-sideline testing
Outcome / reference standard	Concussion not examined
Study design	Case reports
Review sub-topics/Objectives	
Sideline screening tests	Characterise the diagnostic accuracy of sideline clinical tests to detect suspected SRC, including: • Symptoms and clinical signs • Balance tests • Oculomotor tests • Cognitive tests • Multimodal assessments (either joint use of individual sideline tests, or multi-faceted instruments) •
Technology	Determine the utility of technology in the detection of suspected SRC
Integrated head injury assessment protocols	Evaluate integrated protocols for the detection and management of SRC currently used in professional collision sports.

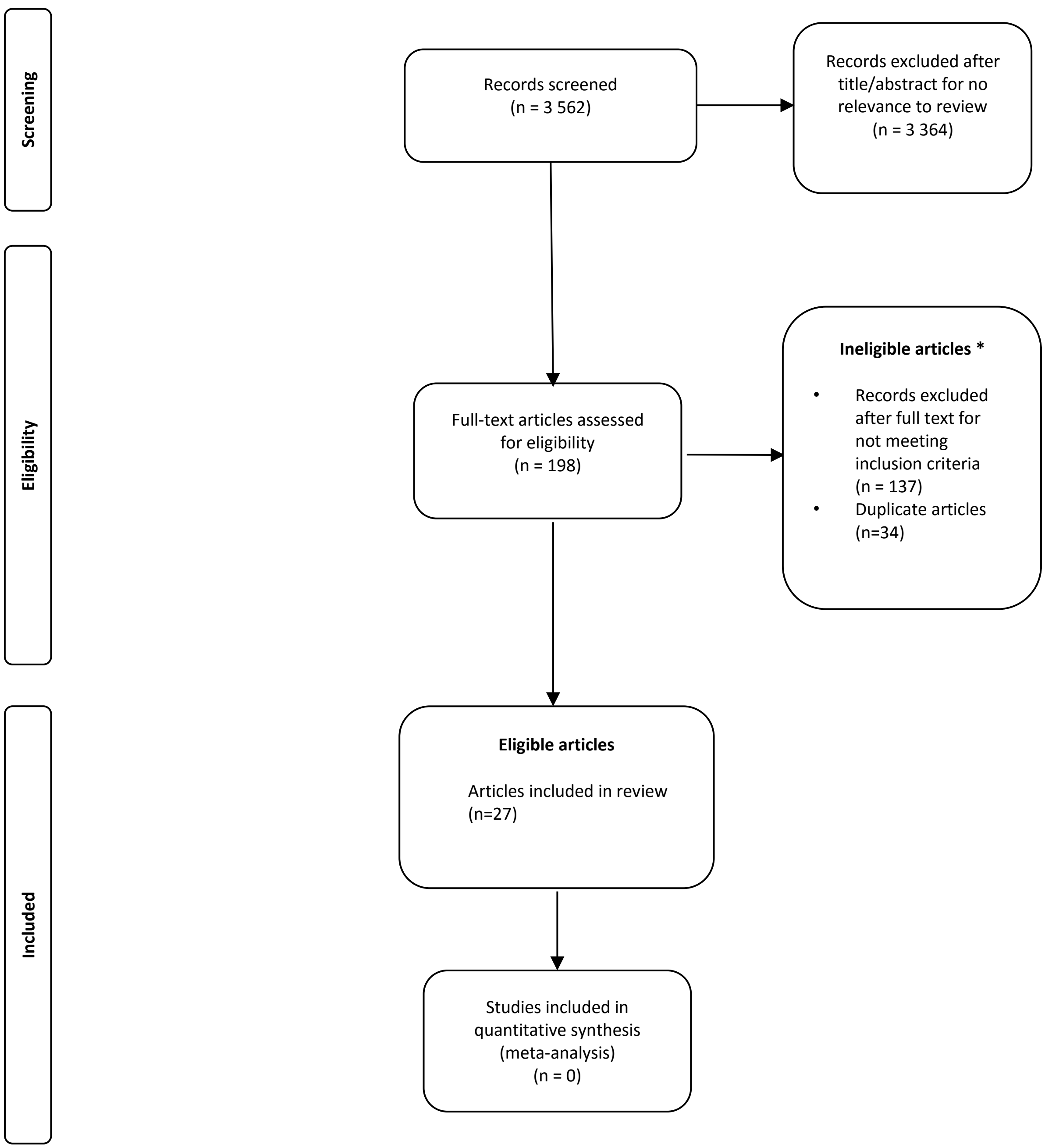
*'sideline' is used generally to denote testing away from the immediate sporting environment e.g. rink side, track-side, locker room, medical room, touch line etc.

RESULTS

Study selection

3 562 citations were screened for eligibility, with the full text of 198 articles retrieved for detailed evaluation. During full text examination 27 studies were found meeting review inclusion criteria: sideline screening assessment (21 studies); integrated diagnostic protocols (1 study); and technology (5 studies). Figure 1 describes the selection of studies in detail.

Fig. 1 Flow of identification, screening, eligibility and inclusion criteria for the literature review of sideline diagnosis of concussion.



Sideline screening tests

Characteristics of included studies

Twenty one studies met review inclusion criteria and reported interpretable data on the diagnostic accuracy of screening tests, either alone or in combination, to identify suspected SRC. Characteristics of the included studies examining sideline assessments are summarised in Table 2.

Risk of bias

Assessment of risk of bias is summarised according to QUDAS-2 domains in Table 3 and Figure 2. Overall risk of bias was high or unclear for all included studies. The predominant limitation was the use of a 'two-gate' study design using healthy controls, which are known to overestimate estimates of test performance.[13 14] Other systematic errors included delayed index testing, inaccurate reference standard assessment by a non-medically trained outcome assessors, and test and diagnostic review, incorporation and attrition biases. Detailed risk of bias evaluations are presented in the web appendix.

Results

The diagnostic accuracy of sideline assessments for detecting suspected concussion are summarised in Figure 3. Studies examining symptoms, the King-Devick (KD) test, and multimodal assessments reported relatively good sensitivity and specificity. Evaluations of balance and cognitive tests described lower sensitivity, but relatively good specificity. However, results were imprecise and heterogeneous for all types of sideline assessments, in addition to the concerns regarding the internal validity. The overall quality of evidence according to GRADE criteria was very low for all classes of sideline tests based on serious concerns regarding inconsistency, imprecision, and risk of bias. Detailed results and evaluation of overall quality of evidence for individual tests is provided in the web appendix.

Table 2. Characteristics of included studies examining sideline screening assessments

Study	Setting	Study design	Sample Size (n=)*	Sport(s)	Level	Mean age (years±SE)	Gender (% male)	Index test(s)	Reference standard
Maddocks 1995[15]	Aus	PCS	56	Australian Football	Professional	NR	100	Individual symptoms, Maddocks questions	Clinical diagnosis
McCrory 2000[16]	Aus	PCS	303	Australian Football	Professional	NR	100	Individual symptoms	Clinical diagnosis
Barr 2001[17]	US	PCS	118	American Football	Varsity High School	18.1 (NR)	NR	SAC	Clinical diagnosis
Erlanger 2003[18]	US	PCS	47	American Football, Ice Hockey, Field Hockey, Wrestling, Soccer, Basketball	School Adolescents	17.6 (SD 2.23)	57	Individual symptoms	NR
McCrea 2001[19]	US	PCS	118	American Football	Varsity High School	19.8±1.3	NR	SAC	Clinical diagnosis
McCrea 2002[20]	US	PCS	91	American Football	Varsity High School	17.5±2.1	NR	SAC	Clinical diagnosis
McCrea 2005[21]	US	PCS	150	American Football	Collegiate Adults	20.04 (SD 1.36)	100	GSC, BESS, SAC	Clinical diagnosis
Echlin 2010[22]	US	PCS	67	Ice Hockey	Junior Adolescents	18.2 ± 1.2	100%	BESS, SAC	Clinical diagnosis + SCAT 2
Galetta K 2011[23]	US	PCS	39	Boxing, mixed martial arts	Amateur - Adult	24	97	KD	MACE
Galetta K 2011b[24]	US	PCS	219	American football, soccer, basketball	Collegiate athletics	20.3±1.4	83	KD	Clinical diagnosis
Barr 2012[25]	US	PCS	90	American football	High school, collegiate	NR	100	CSI, SAC, BESS	Clinical diagnosis

King 2012[26]	NZ	PCS	50	Rugby league	Amateur – Adult	22.4±4.1	100	KD	SCAT 2
Galetta M 2013[27]	US	PCS	27	Ice hockey	Professional	25±5	100	KD, SAC	SCAT 2
Dhawan 2014[28]	US	PCS	141	Hockey	High school athletics	NR	NR	KD	NR
Leong 2014[29]	US	PCS	34	Boxing	Amateur - Adult	25.8±8.3	85	KD	MACE
Fuller 2015[30]	UK, RSA, France	PCS	165	Rugby Union	Professional Adults	NR	100	PSACA1 tool: Maddocks Questions, Symptoms checklist, Mental status assessment, Tandem Stance test	Clinical diagnosis + SCAT 3
Galetta K 2015[31]	US	PCS	243	Ice hockey, lacrosse, Athletics	Amateur – Youth, Collegiate athletics	Youths: 11±3, Adults: 20±1	Youths: 84 Adults: 74	KD, Timed Tandem Gait, SAC	Clinical diagnosis
Leong 2015[32]	US	PCS	127	American football, basketball	Collegiate athletics	19.6±1.2	94	KD	Modified SCAT 2
Marinides 2015[33]	US	RCS	217	American football, lacrosse, soccer	Collegiate athletics	NR	70	KD, BESS, SAC	Clinical diagnosis
Putukian 2015[34]	US	PCS	263	American Football, Rugby Union, Sprint Football, Crew	Collegiate Adults	20.33 (SD 1.74)	67%	SCAT2 symptom checklist, Modified BESS, SAC, SCAT2	Clinical diagnosis
Seidman 2015[35]	US	PCS	337	American football	High school athletics	15.4 ± 1.3	100	KD	SCAT 3

US: United States; NZ: New Zealand; AUS: Australia; GSC: Graded Symptom Checklist; PCS: prospective cohort study; RCS: retrospective cohort study RSA: Republic of South Africa; NR: Not reported; SCAT: Sports Concussion Assessment Tool; MACE: Military Acute Concussion Evaluation; KD: King-Devick; SAC: Standardised Assessment of Concussion; CSI: Concussion Symptom Inventory; BESS: Balance Error Scoring System;

Table 3. Summary of risk of bias across included sideline screening studies

Study	Risk of Bias				
	Patient selection	Index test	Reference standard	Flow and timing	Overall
Maddocks 1995	H	L	L	L	H
Barr 2001	H	?	H	L	H
McCrory 2000	H	?	L	L	H
McCrea 2001	H	?	H	L	H
McCrea 2002	H	?	H	L	H
Erlanger 2003	H	?	?	L	H
McCrea 2005	H	H	H	H	H
Echlin 2010	H	H	H	H	H
Galetta K 2011	L	?	?	H	H
Galetta K 2011b	H	L	H	L	H
Barr 2012	H	H	H	L	H
King 2012	L	?	?	?	?
Galetta M 2013	H	?	?	L	H
Dhawan 2014	H	?	?	L	H
Fuller 2015	L	L	H	L	H
Leong 2014	L	L	L	H	H
Galetta K 2015	H	?	?	H	H
Leong 2015	H	L	H	L	H
Marinides 2015	H	?	?	H	H
Putukian 2015	H	H	L	H	H
Seidman 2015	H	H	L	H	H

H: High; L: Low; ?: Unclear risk of bias.

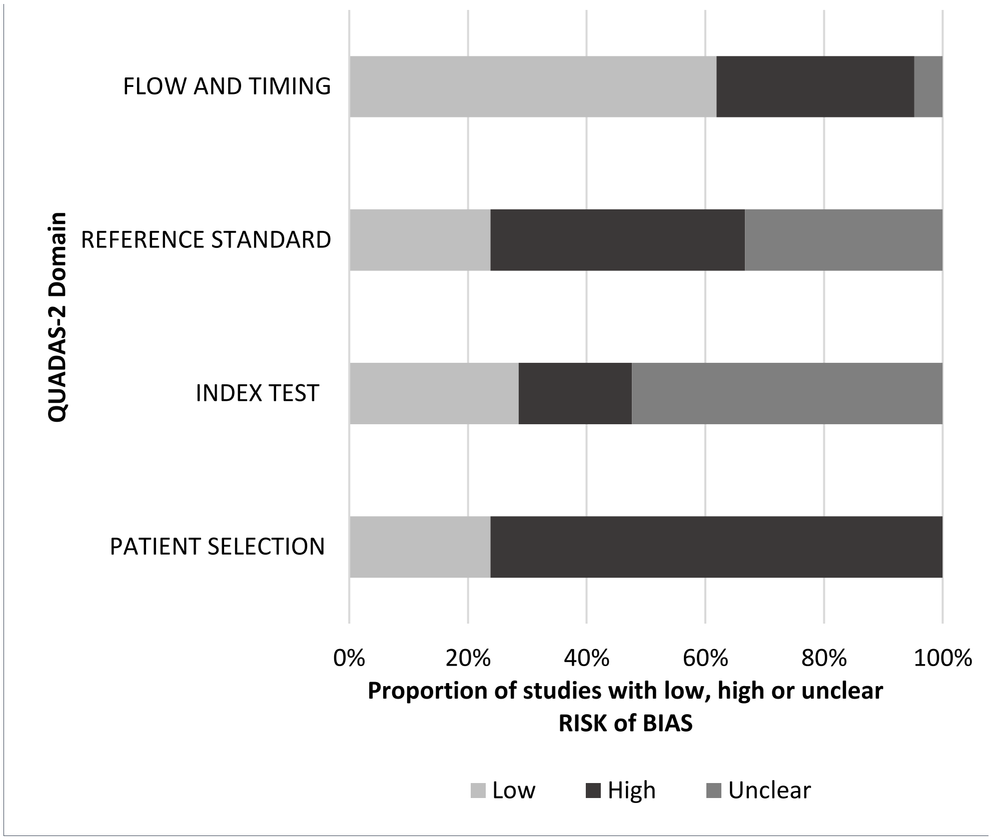
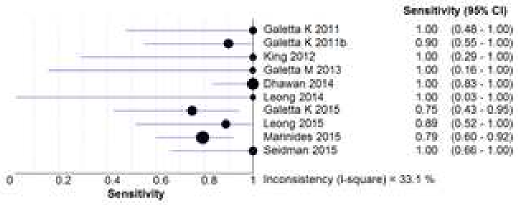
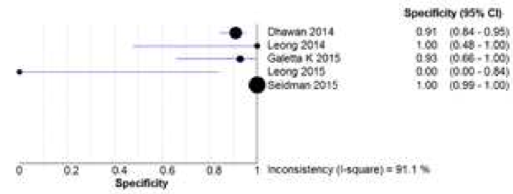


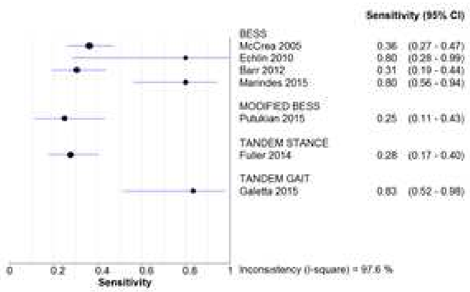
Figure 2. Summary of risk of bias in included studies examining sideline screening

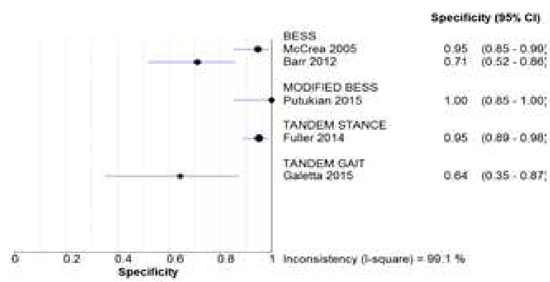
Oculomotor Tests



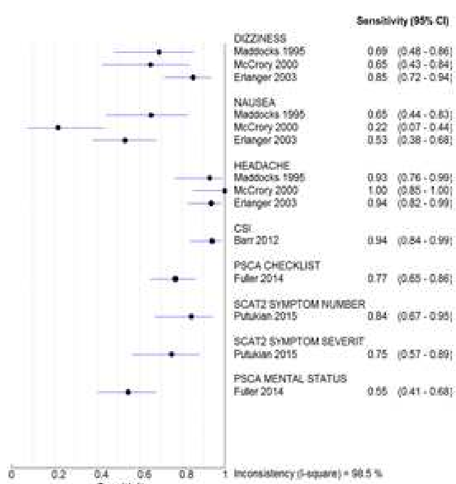


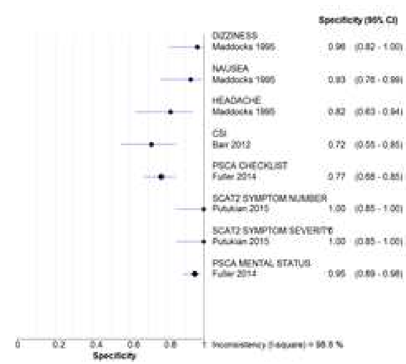
Balance Tests





Symptoms and signs





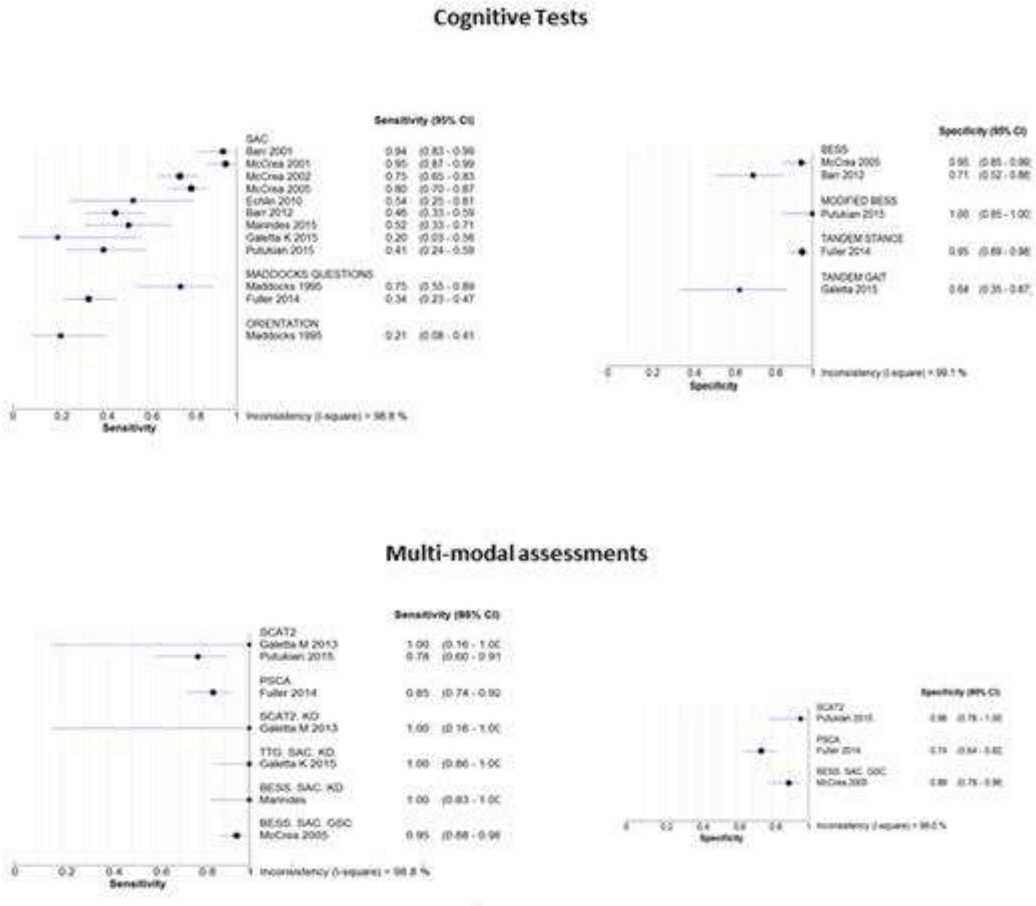


Figure 3. Diagnostic accuracy of sideline screening tests for suspected SRC.

Technology

Five studies met review inclusion criteria and reported interpretable data on the use of a technology in sideline screening for SRC, examining head impact sensors (4 studies) and sideline video review (1 study).[36-40] Overall risk of bias was low for all studies. Reported results indicated that no clinically significant relationship existed between impact magnitude, or location, and concussion $(p>0.05)$. Fuller 2016 reported that sideline video review contributed to identification of 61.5% of significant head impact events and influenced sideline evaluation in 20.4% of cases.[37] The overall GRADE quality of evidence was rated as high for head impact sensors and low for sideline video review. Table 4 summarises the characteristics, risk of bias and main results of included technology studies. Further details on risk of bias and GRADE ratings are provided in the web appendix.

Integrated head injury assessment protocols

No experimental or comparative effectiveness research was identified evaluating the performance of alternative head injury assessment protocols. However, a single study at low risk of bias was retrieved which evaluated a comprehensive system used at the elite level in Rugby Union (Fuller 2016).[37] The major finding was the importance of a multimodal, multitime-based concussion evaluation process incorporating video review to identify significant head impact events and delayed onset concussion. The overall GRADE quality of evidence was rated low, secondary to imprecision and potential inconsistency. Further details on existing integrated head injury assessment protcols in professional sports, and the characteristics of Fuller 2016 are provided in the web appendix.

Table 4. Characteristics, risk of bias and primary findings of included technology studies

Study	Setting	Design	Sample Size (n=)	Sport(s)	Level	Mean age (years±SE)	Technology	Risk of Bias / evidence level	Applicability concerns	Primary finding(s)
Guskiewicz 2007[39]	US	PCS	81	American football	High school	20.2±1.8	HITS	Low	Low	61.5% sensitivity for concussion*
Mihalak 2007[40]	US	PCS	102	American football	Collegiate	19.6±1.6	HITS	Unclear	Low	PPV of 0.35% for concussion†
Greenwald 2008[38]	US	PCS	449	American football	High school	NR	HITS	Low	Low	PPV of 0.3% for concussion*
Broglio 2010[36]	US	PCS	78	American football	High school	16.7±0.8	HITS	Low	Low	PPV of 13.4% for concussion**
Fuller 2016[37]	UK	PCS	49	Rugby Union	Professional	26.5 (SD 3.5)	Sideline video review	Low	Low	Contributed to identification of 61.% of significant head impact events

US: United States; PCS: Prospective cohort study; HITS: Head Impact Telemetry System; PPV: Positive predictive value

*Head impact threshold: linear acceleration >98.9g; **Threshold: >5582.3 rads/s^2 ± 96.1g linear acceleration ± front/side/top impact; † Threshold: linear acceleration >80g

DISCUSSION

Summary of key findings

Studies examining symptoms, the KD test, and multimodal assessments reported high sensitivity and specificity. Evaluations of Balance and cognitive tests described lower sensitivity, but good specificity. However, the overall strength of evidence examining sideline screening tools was of very low quality secondary to high risk of bias, and imprecise and heterogeneous diagnostic accuracy estimates. Studies examining technology a provided a high (head impact sensors) or low (video review) strength body of evidence. Head impact sensors did not provide useful information. Conversely, a multimodal, multi-time based concussion evaluation process incorporating video review appeared to be important for the identification of significant head impact events and the delayed onset concussion.

Interpretation

A meta-analysis was not performed due to the absence of studies at low risk of bias and marked heterogeneity; in accordance with the pre-specified analysis plan a narrative synthesis was therefore conducted. Interestingly, no obvious patterns were evident between study results and design characteristics including sample size, setting, performance level, sport, or risk of bias. This may be due to the inherent generalisability of findings, but could also be explained by biases operating in different directions and to varying magnitudes across different studies.

Notwithstanding the high risk of systematic error, a wide range of settings, sports and age groups were investigated in eligible studies suggesting good external validity of findings. However, in addition to information on diagnostic accuracy; the feasibility, cost and acceptability of alternative sideline tests may be important in applying these results to different settings. The availability of baseline data, testing environment, and influence of the athlete-physician relationship, could also affect generalisability. Importantly, in lower levels of competition where medical staff may be limited, an alternative 'recognise and remove' approach is recommended, with exclusion of the sideline screening stage, and immediate and permanent removal from any further participation when there is any suspicion of concussion.[1 41]

A key concept in sideline assessment is the rapid screening for a suspected concussion, rather than the definitive diagnosis of a head injury. Players manifesting clear on-field observable signs, such as loss of consciousness, ataxia, tonic posturing or post-traumatic seizures can immediately be diagnosed with a concussion and removed from sporting participation. Athletes with the possibility of suspected concussion following a significant head impact event, can alternatively proceed to sideline screening, with a later definitive diagnostic evaluation. Clearly, to allow sufficient time and a suitable environment for testing, this should occur away from the sporting environment, and may necessitate a temporary athlete interchange. The importance of off-field testing is exemplified by findings in professional Rugby where the number of players with confirmed concussion returning to play following their head injury dropped from 56% to 13% following the introduction of the Pitchside Suspected Concussion Assessment (PCSA) that superseded an 'on-the-field-and-on-the run' approach.[30]

Elite contact and collision sports are played at a fast pace in a disorganised environment, where the view of medical staff may be obscured, challenging the evaluation of head impact events. Video review appeared to be helpful in identifying both observable signs of concussion and cases of possible suspected concussion where further assessment off-field is beneficial. Furthermore, evolving and delayed onset concussions have been well described,[37 42] highlighting the importance of careful follow-up after a significant head impact, regardless of a negative sideline screening test or early diagnostic evaluation. Consequently implementation of systematic head injury assessment protocols appear to improve detection and management of the full spectrum of SRC.

Concussion can manifest as a diverse range of somatic, cognitive, behavioural or emotional symptoms; and/or physical signs such as vestibulo-ocular deficits, loss of consciousness and ataxia.[1] It would therefore be expected *ex ante* that multi-modal assessments, evaluating several of these domains, are necessary to maximise detection of different sub-types of SRC. However, with simultaneous testing a net gain in sensitivity usually occurs at the expense of a net loss in specificity.[43] Interestingly, included multi-modal assessment studies reported both high sensitivity and specificity which could suggest either an optimal combinations of tests, or could reflect study biases. Given the absence of definitive evidence on the performance of sideline tests, expert consensus opinion is necessary to guide practice and strongly recommends the use of a multimodal assessment tool, of which the SCAT (now in its 4th version) is the most established, well developed, and studied.[44]

It is important to note that the pre-test probability of concussion will strongly influence the performance of sideline screening tests.[45] In settings with high prevalence of concussion, or high test thresholds, the negative predictive value of sideline tests will fall. High sensitivity and specificity would consequently be necessary to ensure the detection of a satisfactory proportion of cases. Conversely, indiscriminate testing, with a lower pre-test probability of concussion, would result in higher negative predictive values, but worsening numbers of false positives. Such a safety-first approach might be preferred in non-elite settings.

Consistency with other studies or reviews

There have been a large number of narrative reviews, position statements and editorials that have previously examined the role of sideline screening tests or technology in the detection of sports related concussion. Although these articles are inherently limited by a lack of defined inclusion criteria, systematic search strategies and transparent risk of bias assessment, their conclusions are broadly consistent with the current systematic review. For example Eckner et al 2010 stated that 'multiple assessment tools are available, with no single tool showing clear superiority. Many tools remain based more on expert opinion than rigorous scientific evaluation'.[46]

Six related systematic reviews were also identified during the literature searches, comprising examination of symptom checklists (Alla 2009);[47] SCAT 2/3 (Yengo-Khan 2016);[48] BESS (Bell 2011);[49] KD test (Hunt 2015, Galetta K 2016);[50 51] and sideline testing in general (King 2014).[52] Although the review questions were not directly comparable, including delayed non-sideline testing and additional examination of test reliability, similar studies were often included and conclusions concurred with the current study in Alla 2009, Yengo-Khan 2016, Bell 2013, and Hunt 2015. For example Alla 2009 noted that 'There is little information available on the derivation or psychometric properties (eg, sensitivity, reliability etc) of the various symptom scales'; and Yengo-Khan 2016 observed that 'the sensitivity and specificity of the SAC has been reported sparsely'. Conversely, in contrast to the current findings, Galetta K 2016 and King 2014 concluded that the KD test can successfully identify SRC on the sideline. This divergent opinion is explained by the absence of any risk of bias assessment for constituent studies included in their reviews, resulting in the KD test being interpreted as having high sensitivity and specificity whereas the quality of evidence presented did not justify this.

Implications for research

There is an absence of valid research confirming the diagnostic accuracy and impact on improving outcomes of currently used sideline screening tests. Adequately powered diagnostic accuracy studies are therefore recommended that enrol a representative sample of athletes with suspected concussion following non-trivial head impact events. Ideally, once the diagnostic accuracy and optimal threshold of sideline tests have been confirmed, comparative effectiveness studies would investigate whether important outcomes are improved. Further research is also recommended to investigate the impact of integrated head injury assessment protocols and sideline video review for the evaluation of head impact events. Further research could usefully examine novel sideline screening tests such as reaction times, or investigate the utility of tablet software applications as an adjunct to sideline concussion screening.

Review limitations

There are a number of potential methodological weaknesses which could limit the validity of this systematic review. Due to time constraints, hand searching of journals and conference proceedings was not performed and regional bibliographic databases were not included raising the potential for publication bias. Decisions on study relevance, information gathering, and validity were un-blinded and could potentially been influenced by pre-formed opinions. Furthermore, data extraction and risk of bias assessment was not performed in duplicate (i.e. two truly independent reviews), with the second reviewer checking the assessment of the first reviewer. Finally, assessment of reference standard bias was challenged by the lack of a convincing diagnostic gold standard.

CONCLUSIONS

Based on this systematic review of the literature, an evidence-based recommendation for any individual screening test or protocol is not possible. The recognition of suspected concussion is therefore best approached using multi-modal testing guided via expert consensus. The SCAT currently represents the most well established and rigorously developed instrument available for sideline assessment. The addition of video review could potentially offer a promising approach to improve identification and evaluation of significant head impact events, and a multi-time-based concussion evaluation process appears to be important to detect delayed onset SRC. The KD test shows promise as a sideline screening test but requires adequately powered diagnostic accuracy studies which avoids a two-gate design with healthy controls, and enrols a representative sample of athletes with suspected concussion. Collaboration between sporting codes to rationalise multimodal diagnostic sideline protocols may help facilitate more efficient application and monitoring. Current evidence does not support the use of impact sensor systems for real-time concussion screening.

REFERENCES

1. 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. British journal of sports medicine 2013;**47**(5):250-8

2. Helmy A, Agarwal M, Hutchinson PJ. Concussion and sport. BMJ (Clinical research ed.) 2013;**347**:f5748

3. D CH, Zaremski JL, Vincent HK, et al. Effect of neurocognition and concussion on musculoskeletal injury risk. Current sports medicine reports 2015;**14**(3):194-9

4. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. Neurosurgery 2005;**57**(4):719-26; discussion 19-26

5. McKee AC, Cantu RC, Nowinski CJ, et al. Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. Journal of neuropathology and experimental neurology 2009;**68**(7):709-35

6. Higgins J, Green SP. *Cochrane handbook for systematic reviews of interventions*. Oxford: Wiley-Blackwell, 2008.

7. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ (Clinical research ed.) 2009;**339**:b2700

8. Leeflang MM, Deeks JJ, Gatsonis C, et al. Systematic reviews of diagnostic test accuracy. Annals of internal medicine 2008;**149**(12):889-97

9. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Annals of internal medicine 2011;**155**(8):529-36

.

10. Lewis S, Clarke M. Forest plots: trying to see the wood and the trees. BMJ (Clinical research ed.) 2001;**322**(7300):1479-80

11. Higgins JP, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. BMJ (Clinical research ed.) 2003;**327**(7414):557-60

12. Schunemann HJ, Oxman AD, Brozek J, et al. Grading quality of evidence and strength of recommendations for diagnostic tests and strategies. BMJ (Clinical research ed.) 2008;**336**(7653):1106-10

13. Rutjes AW, Reitsma JB, Vandenbroucke JP, et al. Case-control and two-gate designs in diagnostic accuracy studies. Clinical chemistry 2005;**51**(8):1335-41

14. Lijmer JG, Mol BW, Heisterkamp S, et al. Empirical evidence of design-related bias in studies of diagnostic tests. JAMA : the journal of the American Medical Association 1999;**282**(11):1061-6

15. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine 1995;**5**(1):32-5

16. McCrory PR, Ariens T, Berkovic SF. The nature and duration of acute concussive symptoms in Australian football. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine 2000;**10**(4):235-8

17. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. Journal of the International Neuropsychological Society : JINS 2001;**7**(6):693-702

18. Erlanger D, Kaushik T, Cantu R, et al. Symptom-based assessment of the severity of a concussion. J Neurosurg 2003;**98**(3):477-84

19. McCrea M. Standardized Mental Status Testing on the Sideline After Sport-Related Concussion. Journal of athletic training 2001;**36**(3):274-79

20. McCrea M, Kelly JP, Randolph C, et al. Immediate neurocognitive effects of concussion. Neurosurgery 2002;**50**(5):1032-40; discussion 40-2

21. McCrea M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. Journal of the International Neuropsychological Society : JINS 2005;**11**(1):58-69

22. 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. Neurosurgical focus 2010;**29**(5):E5

23. 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**(17):1456-62

24. 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. Journal of the neurological sciences 2011;**309**(1-2):34-9

25. Barr WB, Prichep LS, Chabot R, et al. Measuring brain electrical activity to track recovery from sport-related concussion. Brain injury : [BI] 2012;**26**(1):58-66

26. 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. Journal of the neurological sciences 2012;**320**(1-2):16-21

27. 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. Journal of the neurological sciences 2013;**328**(1-2):28-31

28. Dhawan P SA, Tapsell L, Adler J, Galetta S, Balcer L, Dodick D. King-Devick Test Identifies Symptomatic Concussion in Real-time and Asymptomatic Concussion Over Time. Neurology Clinical Practice 2014;**82**(10):S11

29. Leong DF, Balcer LJ, Galetta SL, et al. The King-Devick test as a concussion screening tool administered by sports parents. The Journal of sports medicine and physical fitness 2014;**54**(1):70-7

30. Fuller GW, Kemp SP, Decq P. The International Rugby Board (IRB) Pitch Side Concussion Assessment trial: a pilot test accuracy study. British journal of sports medicine 2015;**49**(8):529-35

31. Galetta KM, Morganroth J, Moehringer N, et al. Adding Vision to Concussion Testing: A Prospective Study of Sideline Testing in Youth and Collegiate Athletes. Journal of neuro-ophthalmology : the official journal of the North American Neuro-Ophthalmology Society 2015;**35**(3):235-41

32. Leong DF, Balcer LJ, Galetta SL, et al. The King-Devick test for sideline concussion screening in collegiate football. Journal of optometry 2015;**8**(2):131-9

33. Marinides Z, Galetta K, Andrews C, Wilson J, Herman D, Robinson C, Smith M, Bentley B, MD, Galetta D, Balcer L, Clugston J. Vision testing is additive to the sideline assessment of sports-related concussion. Neurology Clinical Practice 2015;**5**(1):24-34

34. 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. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine 2015;**25**(1):36-42

35. Seidman DH, Burlingame J, Yousif LR, et al. Evaluation of the King-Devick test as a concussion screening tool in high school football players. Journal of the neurological sciences 2015;**356**(1-2):97-101

36. Broglio SP, Schnebel B, Sosnoff JJ, et al. Biomechanical properties of concussions in high school football. Medicine and science in sports and exercise 2010;**42**(11):2064-71
.
37. Fuller CW, Fuller GW, Kemp SP, et al. Evaluation of World Rugby's concussion management process: results from Rugby World Cup 2015. British journal of sports medicine 2016

38. Greenwald RM, Gwin JT, Chu JJ, et al. Head impact severity measures for evaluating mild traumatic brain injury risk exposure. Neurosurgery 2008;**62**(4):789-98; discussion 98

39. Guskiewicz KM, Mihalik JP, Shankar V, et al. Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. Neurosurgery 2007;**61**(6):1244-52; discussion 52-3

40. Mihalik JP, Bell DR, Marshall SW, et al. Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. Neurosurgery 2007;**61**(6):1229-35; discussion 35

41. Hodgson L, Patricios J. Clarifying concussion in youth rugby: recognise and remove. British journal of sports medicine 2015;**49**(15):966-7

42. Scorza KA, Raleigh MF, O'Connor FG. Current concepts in concussion: evaluation and management. American family physician 2012;**85**(2):123-32

43. Doubilet PM, Cain KC. The superiority of sequential over simultaneous testing. Medical decision making : an international journal of the Society for Medical Decision Making 1985;**5**(4):447-51

44. SCAT3. British journal of sports medicine 2013;**47**(5):259

45. Akobeng AK. Understanding diagnostic tests 1: sensitivity, specificity and predictive values. Acta paediatrica (Oslo, Norway : 1992) 2007;**96**(3):338-41

46. Eckner JT, Kutcher JS. Concussion symptom scales and sideline assessment tools: a critical literature update. Current sports medicine reports 2010;**9**(1):8-15

47. Alla S, Sullivan SJ, Hale L, et al. Self-report scales/checklists for the measurement of concussion symptoms: a systematic review. British journal of sports medicine 2009;**43 Suppl 1**:i3-12

48. Yengo-Kahn AM, Hale AT, Zalneraitis BH, et al. The Sport Concussion Assessment Tool: a systematic review. Neurosurgical focus 2016;**40**(4):E6

49. Bell DR, Guskiewicz KM, Clark MA, et al. Systematic review of the balance error scoring system. Sports health 2011;**3**(3):287-95

50. Hunt AW, Mah K, Reed N, et al. Oculomotor-Based Vision Assessment in Mild Traumatic Brain Injury: A Systematic Review. The Journal of head trauma rehabilitation 2015

51. Galetta KM, Liu M, Leong DF, et al. The King-Devick test of rapid number naming for concussion detection: meta-analysis and systematic review of the literature. Concussion 2015

52. King D, Brughelli M, Hume P, et al. Assessment, management and knowledge of sport-related concussion: systematic review. Sports medicine (Auckland, N.Z.) 2014;**44**(4):449-71