



This is a repository copy of *International study of video review of concussion in professional sports*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/136749/>

Version: Accepted Version

Article:

Davis, G.A., Makdissi, M., Bloomfield, P. et al. (15 more authors) (2019) International study of video review of concussion in professional sports. *British Journal of Sports Medicine*, 53 (20). pp. 1299-1304. ISSN 0306-3674

<https://doi.org/10.1136/bjsports-2018-099727>

© Author(s) (or their employer(s)) 2018. This is an author produced version of a paper subsequently published in *British Journal of Sports Medicine*. Uploaded in accordance with the publisher's self-archiving policy.

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



eprints@whiterose.ac.uk
<https://eprints.whiterose.ac.uk/>

The International study of Video review of concussion in Professional Sports

Gavin Davis^{1,2}, Michael Makdissi^{1,3}, Paul Bloomfield⁴, Patrick Clifton⁵, Ruben Echemendia⁶, Eanna Falvey⁷, Gordon Fuller⁷, Gary Green⁸, Peter Harcourt⁵, Thomas Hill⁹, Nathan McGuirk⁴, Willem Meeuwisse⁶, John Orchard⁹, Martin Raftery⁷, Allen K Sills¹⁰, Gary Solomon^{10,11} Alex Valadka⁸ and Paul McCrory¹

1. Florey Institute of Neuroscience and Mental Health, Melbourne, Victoria, Australia
2. Neurosurgery Department, Cabrini and Austin Hospitals, Melbourne, Victoria, Australia
3. La Trobe Sport and Exercise Medicine Research Centre, La Trobe University, Melbourne, Victoria, Australia
4. National Rugby League
5. Australian Football League
6. National Hockey League
7. World Rugby
8. Major League Baseball
9. Cricket Australia
10. National Football League, New York, USA
11. Department of Neurosurgery, Vanderbilt University Medical Center, Nashville, TN, USA

Corresponding author:

Gavin Davis
Suite 53 – Neurosurgery
Cabrini Malvern
Wattletree Road, Malvern
Victoria
Australia

Ph +613 9509 2411

Fax +613 9509 6811

Email gavin.davis@me.com

Abstract

Background – Video review has become an important tool in professional sporting codes to help sideline identification and management of players with a potential concussion.

Aim – To assess current practices related to video review of concussion in professional sports internationally, and compare protocols and diagnostic criteria used to identify and manage potential concussions.

Methods – Current concussion management guidelines from professional national and international sporting codes were reviewed. Specific criteria and definitions of video signs associated with concussion were compared between codes. Rules and regulations adopted across the codes for processes around video review were also assessed.

Results – Six sports with specific diagnostic criteria and definitions for signs of concussion identified on video review participated in this study (Australian Football, American Football, World Rugby, Cricket, Rugby League and Ice Hockey). Video signs common to all sports include *lying motionless/loss of responsiveness* and *motor incoordination*. The video signs considered by the majority of sports as most predictive of a diagnosis of concussion include *motor incoordination, impact seizure, tonic posturing* and *lying motionless*. Regulatory requirements, sideline availability of video, medical expertise of video reviewers and use of spotters differ across sports and geographical boundaries. By and large these differences reflect a pragmatic approach from each sport, with limited underlying research and development of the video review process, in some instances.

Conclusions - The use of video analysis in assisting medical staff with the diagnosis or identification of potential concussion is well established across different sports internationally. The diagnostic criteria used and the expertise of the video review personnel are not clearly established, and research efforts would benefit from a collaborative harmonisation across sporting codes.

Introduction

Sport-related concussion (SRC) is common, with an incidence in professional sports of up to 18 concussions per 1000 athlete hours.^{1,2} Yet, despite being a common neurological injury, the diagnosis of SRC is often challenging for the clinician, especially on the sideline.³ This task can be even more complex and difficult in professional and elite sports where the speed of the game is faster (with possibly corresponding greater force of impact), play is often more congested and clinical decisions need to be made quickly. The definition of SRC is complex⁴, which is exacerbated by the absence of an objective and reliable biomarker for the diagnosis of concussion. As such, SRC remains a clinical diagnosis. Obvious signs such as loss of consciousness present in fewer than 10% of cases,⁵ and the diagnosis of SRC is often not easily apparent, yet failing to make an accurate diagnosis can have significant short and long term consequences for the athlete.⁶

Early signs of SRC may be brief and may resolve completely by the time that the medical staff arrive to assess the player. In the past, video review of potential concussive incidents has not been available to team medical staff on the sideline, although it was available to the public watching the game via broadcast feeds. When shown on slow-motion replay, often from multiple angles by the broadcaster, brief early signs of concussion (such as staggers) are more easily observed by broadcast viewers and expose the medical staff for “missing” a concussion. To assist the team physicians with assessing possible concussive injuries, many sporting bodies have introduced the use of video for real-time assessment, and for post-hoc analysis and review. Video review affords the viewer the opportunity to watch the incident from multiple angles, repeatedly, in slow motion, and to assess biomechanical and clinical features of the incident.

Professional sporting codes around the world have introduced video assessment for SRC concurrently. By and large, sports have followed a pragmatic approach, dictated more by cost and availability of resources than being driven by empirical scientific research. Practically, sports have adopted different management strategies around the in-game video review process, including the availability of broadcast feed that can be controlled by the team medical staff, addition of concussion “spotters”, use of a video “tent” which allows a distraction-free environment for viewing the video, etc. Consequently, the approach by various professional sporting organisations with regard to the role of video review in concussion assessment and management has been variable.⁷⁻²²

There are a number of signs of SRC that may be observable on video. These range from signs that are highly suggestive of a diagnosis of SRC (such as impact seizures, tonic posturing and motor incoordination), and others that are less specific (such as “loss of responsiveness”, facial injury or “slow to get up”).⁸ One of the current limitations of video review however is that observable signs have limited sensitivity and specificity when compared to a clinical diagnosis of SRC.^{9,11,15,17} Some sports have adopted a conservative approach where by the presence of signs highly suggestive of a SRC requires “immediate and permanent removal from play”, whereas in other sports, video signs are used to identify a potential SRC but further clinical assessment is required before the diagnosis is firmly established. Consequently, the interpretation of the video signs associated with SRC and the implications for management currently vary from sport to sport.

It is likely that clinical signs of a possible concussion, observable with video review, are common to all sports, although sport-specific signs may be possible. There are other differences between sports that may impact the utility of individual signs, including use of protective equipment, size of sporting field, linear or 360° play, number of athletes in play, location of cameras, etc. For example, signs such as “blank and vacant look” may be useful in some sports, but may be difficult to ascertain in others where helmets obscure facial expression of the athlete. It is important to examine whether commonalities should exist across sports in essential elements of video review.

The objective of this study was to assess practices related to video review of concussion in professional sports internationally, and compare protocols and criteria used to identify and manage potential concussions, in order to help establish a common standard and improve the identification and management of SRC on game-day.

Methods

Senior medical advisers and sport chief medical officers from major international sporting codes, including Australian Football League (AFL), Cricket Australia (CA), Major League Baseball (MLB), National Football League (NFL), National Hockey League (NHL), National Rugby League (NRL) and World Rugby (WR) were purposively sampled and invited to participate in the study. As a census sample of major sporting codes, a sample size calculation was not necessary. Each sport completed a standardised questionnaire assessing the following topics, as they pertain to the use of video review for concussion assessment in their sport:

- The source of the video feed
- Video signs that result in permanent removal from play
- Video signs that results in removal from play for further assessment
- Definitions of the video signs
- Biomechanical criteria
- Qualification/status of video reviewers
- Use of spotters
- Time limits and locations for video review
- Equipment provided for video review
- Education provided for video staff
- Laws of the game and audit

Questionnaire content was informed by a literature review of published studies evaluating video review in sport and consultation with sports medicine experts. Questions included both closed and open questions. The survey was presented in Microsoft Excel and circulated by email between November 2017 and December 2017. Reminders were sent if there was no response by 4 weeks. Respondents provided consent to use their data. As the data content of this study is available in the public domain and does not contain any patient data, research ethics committee approval was not required.

The data were extracted independently by 2 researchers (GD and MM) according to pre-defined data definitions and tabulated to determine which video signs are common to all sports, which are common to most sports, and which are sport specific. Disagreements were resolved by arbitration, with referral to a 3rd researcher if required. A narrative synthesis was performed to assess the consistency of definitions used across the sports, and to identify which signs and definitions should be incorporated into a “core” group of video signs, and which should be “optional” or sport-specific.

Results

Seven sports invited to participate responded to the study. Major League Baseball is yet to incorporate video review into their concussion management protocols, and therefore MLB was excluded from further data synthesis, with six sports included in the final analysis.

The questionnaire was completed by medical personnel from each sport. All six sports are currently using live, in-game video review as part of their concussion protocols. Competition organised by three out of the six sporting bodies is played in a single country (AFL, CA and NRL in Australia), with one sporting body running competition across two countries (NHL - Canada and United States of America), one competition playing games across three countries (NFL – USA, Mexico and England) and one sporting body running competition across multiple countries (World Rugby – with 102 Member Unions and 17 Associate Unions).

Personnel

In all sports, experienced doctors are responsible for reviewing the video footage. NFL and NHL use Certified Athletic trainers (ATC) to watch the video feed and identify any suspicious head injury events (i.e. act as concussion “spotters”). In the NFL, the ATC spotters typically relay the video and their commentary to the sideline medical staff who must also view the video. On occasion, the sideline staff will initiate the review process by contacting the ATC spotter and asking them to obtain the video of a certain play so that the injury mechanism may be further explored. Similarly, the NHL uses ATC as the primary video spotters, following which team physicians review the video in the medical room. Additionally, the NHL uses off-ice officials who have been trained as spotters to view the game live within the arena from a vantage point where they can see the entire ice surface. WR also allows for other “appropriately trained” healthcare professionals (e.g. physiotherapist) to act as video spotters. Currently NRL have an informal arrangement where the video technician may also act as a spotter, and are trialling further spotter roles both at the ground and at a central video bunker.

WR also has an independent match day doctor who is involved in the process of video review and NFL has an Unaffiliated Neurotrauma Consultant (UNC) involved in the process on each sideline (and will have a third UNC located in the booth with the ATC Spotters starting in the 2018-19 season). CA uses a single doctor at matches, being the team doctor for international matches and an independent match day doctor at domestic matches.

Video source

Broadcast vision is used exclusively in two sports, CA, and NFL. NHL and AFL use the Hawk-Eye system,²³ which allows multiple camera views and the video clip can be manipulated (including rewinding, slow motion, and enlarging the field of view). NRL had used a combination of Broadcast footage, and commenced using the Hawk-Eye system in 2018. World Rugby uses a variety of video sources (including Hawk-Eye or equivalent systems; e.g. EVS, MyPlayXPlay, VoGo)²⁴⁻²⁶ or broadcast footage, with the video source being dictated by the tournament organisers.

Equipment and location

Four sports (AFL, NHL, NRL, WR) use a video monitor that can be manipulated by the viewer. AFL and NRL have the video equipment located exclusively on the sidelines without the provision of a specific distraction free environment. NFL has a video booth above the field (press box), that provides a private viewing area for the ATC spotters, who are then connected via headphones to the sideline medical staff; a sideline video monitor is provided to medical staff that shows the same views used by the concussion spotters. It is a requirement of the NFL concussion protocol that the injury video review is a part of EVERY concussion evaluation done either on the sideline or in the locker room.²⁷ The medical treatment room is used for video assessment in the NHL, thus providing a distraction free environment. For CA, there is no standard/formal place set aside for medical assessment of video and it varies depending on the broadcast conditions. In WR the video review occurs in a neutral area between the team sideline areas, as well as in the medical room.

Video signs of possible concussion

The video signs used for decisions for “*Permanent removal from play*”, and for “*Requires removal and assessment*” are listed in Table 1. *Permanent removal from play* mandates that the athlete may not return to play that day, whereas, *Removal and assessment* requires sideline medical evaluation to confirm the diagnosis and disposition of the athlete. The two video signs common to every sport are *Loss of consciousness/responsiveness/Lying motionless* and *Motor incoordination*. The video signs common to most sports are *Impact seizure, Tonic posturing* and *No protective action*.

Whilst most sports mandate permanent removal from same-game play based on some video signs, one sport does not mandate permanent removal based on video signs but does have a protocol on mandatory removal, a standardised assessment and physician clinical decision making regarding diagnosis.

Definitions of video signs

The definitions of each sign used by the different sports are presented in Table 2.

Protocol

No sport has a time limit for the video assessment. In WR the video review is used initially to identify any suspicious head impact events. A second video review is then undertaken off-field to identify immediate removal criteria (Criteria 1). If there are no Criteria 1 signs evident on video, the player undergoes an off-field assessment. Similarly, in NFL, the concussion spotter can call a “Medical timeout” and contact either the team medical staff and/or an on field Official (Side Judge) via the Official-to-Official communication system following head impact events with signs of concussion, if the injury was not noted by the

sideline medical staff and play would otherwise continue without a medical evaluation for the potentially injured player.

Biomechanical video criteria of concussion

Only three of the sports include a biomechanical video criterion of concussion. The definitions provided involve an impact or trauma to the head, neck or body (with force transmitted to the head).

Compliance

Four sports (AFL, NFL, NRL and WR) include video assessment in the laws of the game. In two sports, it is included as part of the concussion protocol, but there are no specific corresponding regulatory laws or rules. In AFL and NRL the team can be fined by the sport governing body for not following concussion protocols, and in the NFL all concussion protocol violations are investigated jointly with the players union, and fines and other punishments may be applied for violations. The NHL may fine individual Clubs for violations of the concussion protocol. Similarly, in WR cases may be referred to the Tournament Disciplinary Committee.

All sports have an audit process for monitoring compliance with the video assessment and concussion protocols. The reviews are conducted by nominated independent trained medical professionals. Information is provided to concussion spotters and team medical staff where appropriate. Furthermore, WR Game analysts review match footage post-game for any missed significant head impact events, and similar review processes are included in NRL and AFL.

Education

NFL, NHL and WR have education modules for their team medical staff regarding the use of video assessment. The NHL also has education modules for their central and in-area game spotters. AFL do not have specific education modules but run yearly meetings for their medical staff with review and discussion of cases from the season. NRL utilise Elite Head Injury/Concussion Protocols online module, which includes video assessment training. NFL does yearly annual meetings for medical personnel as well. Cricket Australia has an annual conference to educate medical officers on concussion management but no specific education modules on video assessment.

Discussion

The evolution of use of video technology in concussion assessment in elite sports has proceeded across different sports, in different continents, independent of each other, and whilst there are numerous subtle differences in game day practicalities, there are many similarities across the sports regarding the neurological criteria used.

Recent studies on the video signs associated with concussion have demonstrated good to fair inter-rater reliability on coding video signs of concussion. Similarly, the sensitivity and specificity of video signs were variable when compared to a clinical diagnosis of SRC,^{9 11 15 17} Some of the limitations noted in these studies however included ambiguity in the early definitions and a reliance on broadcast view (which often failed to show a clear view of the

player following impact).^{9 11 15 17} In some cases, the broadcast views alone are insufficient as they cannot show all players on the field at all times, and thus, some injuries may be missed.

The current study highlights the differences in the approach to video assessment that have evolved in several major national and international sports. Whilst there are many similarities in the definitions and processes introduced by the sports to identify a possible concussion, there may be significant benefit in developing a common standard to help improve the identification and management of SRC on game-day.

Video Signs of Concussion

Loss of Consciousness/Responsiveness/Lying Motionless and *Motor Incoordination* are video signs common to all sports. Whilst there are some subtle differences in definitions used across the sports, each sport is referring to a similar neurological entity. It is evident that most sports use the term *Loss of Consciousness*, however, assessment of conscious state requires direct clinical examination by a health practitioner (as occurs in the assessment of the Glasgow Coma Scale), and cannot be solely determined from video. *Loss of consciousness* and *Loss of responsiveness* are therefore best used as clinical signs, and the preferred term in assessing video signs of concussion is *Lying motionless*. The strict definition of *Lying motionless*, particularly regarding duration of motionless, has not been adequately examined, and requires further investigation.

Motor Incoordination is a video sign common to all sports, yet two-thirds of the sports recommend permanent same-game removal from play, and the other sports require removal and assessment when this video sign is present. There are some subtle definitional and terminology differences across the sports, with terms such as “ataxia”, “staggering gait”, “loss of balance”, “stumbles” and “clumsiness” all referring to the same entity, namely motor incoordination. Terms that incorporate gait in their nomenclature can mislead, because often the motor incoordination is observed in the athlete on their hands and knees, attempting to rise from the ground/field, and before they commence with gait. Therefore, definitions and terms that only assess gait will miss the common entity of motor incoordination in an athlete not in the action of running/walking/skating. Although motor incoordination may be due to other pathology (e.g. injury to the vestibular apparatus, lower limb injury), this is difficult to establish with clinical certainty on the sidelines. Until such time that a direct, objective sideline diagnostic test of concussion is established, it is recommended that sports adopt a conservative approach. Consequently, it is recommended that, in the absence of a definitive alternate cause (e.g. lower limb musculoskeletal injury), an athlete with definite motor incoordination following head trauma should be considered to have a concussion and permanently removed from play, or in ice-based sports with skates, be subject to a mandatory comprehensive off-ice evaluation.

Impact Seizure and Tonic Posturing are included in the criteria for all sports, except in NHL. Impact seizures following head trauma are uncommon²⁸, but tonic posturing has been demonstrated to be common in sports such as Australian football.²² Tonic posturing is often brief and can be difficult to identify. It is possible that the use of medical personnel to assess video, in some sports, experienced in the assessment of seizures and neurological diseases, heightens clinician awareness of these signs, and clinical experience affords sufficient

confidence to interpret these signs on video. Conversely, in sports using personnel with less neurological experience, it is possible that there is less confidence in identifying these signs on video, or, if unfamiliar with these signs, will not look for them, and thus not include them in their results. Alternatively, it is possible that there are significant sport-specific differences in the occurrence or frequency of Impact Seizure or Tonic Posturing. Whether the use of helmets or other body protection equipment in some sports modifies the appearance of such signs is not yet clear, and requires further investigation.

The video sign of *No Protective Action, uncontrolled fall to the ground and cervical hypotonia* are phrases that describe the same phenomenon where by the player does not use any protective manoeuvres as they fall to the ground, implying that they have already lost consciousness.⁸ In a detailed reliability study on video signs in AFL, it was noted that players could be “floppy” or “stiff” as they fell to the ground and failed to protect themselves.⁸ It is acknowledged that *No Protective Action – Stiff* is actually the presence of tonic posturing that occurs on impact, before the athlete lands on the ground, and it is therefore not surprising that there is a strong correlation between sports that incorporate these two video signs into their protocols. The video sign *No Protective Action – floppy* is identical to the “ragdoll” sign, often described by video assessors, however, it is preferable to use the more descriptive terms, rather than the term ragdoll, because it is less ambiguous, and allows for clear differentiation between those who fall while flaccid (floppy) and tonic (stiff). Two sports use the additional term *Cervical Hypotonia* when assessing video for *No Protective Action*. In some circumstances a player with *No protective action - floppy* may have the arms held in a tackle such that the flaccid characteristic is only identified superior to the cervicothoracic junction. Some refer to this as *Cervical hypotonia*, however this term may be misleading as it may suggest that the hypotonia is restricted to the cervical region only. There may be merit in sub-categorising *No protective action-floppy*, as *arms-free* or *arms-held*, to clarify the terminology in this group.

Blank and Vacant Look is a sign that, when present, is highly correlated with the diagnosis of concussion,⁸ however it is a sign that can be difficult to assess with video, because it requires an un-obstructed video view of the athlete’s face and eyes, and can be obscured by the presence of helmets and face-shields. Further, familiarity with the individual athlete is important, because of the variability in athletes’ normal appearance, and as such, a team doctor familiar with the athlete is at an advantage in identifying this video sign.

Disorientation and *Confusion/Behaviour Change* are used by a few sports, however these signs are best elicited during the neurological examination. These signs can be inferred, to a degree, by odd athlete behaviour, such as running in the wrong direction on the field, but disorientation, from a neurocognitive perspective, requires formal clinical examination, and cannot be determined from video alone.

The video signs of *Slow to Get Up* and *Clutching at Head* are used by several sports for removal and assessment, but no sport incorporates these signs into criteria for permanent same-game removal from play. They may be useful markers that an event has occurred, and warrants further medical attention, but are non-specific for the diagnosis of concussion. The video sign *Facial Injury/ suspected facial fracture* is also not sufficiently specific to the

diagnosis of concussion, and no sport incorporates it into the criteria for permanent same-game removal from play.

It is apparent that there are very few differences in the definitions used by the different sporting bodies, and it is likely that, whilst each sport developed their processes independently, clinicians advising sporting bodies on protocols would have appraised themselves of the published literature at the time, and therefore there was some degree of acceptance of published definitions, where it was considered that the definitions were appropriate for that sport, and could not be improved upon. Some definitions are different across the sporting spectrum, and this is most likely due to difficulties in creating video analogies for neurological bedside clinical examination findings. For example, *Loss of Consciousness/Responsiveness* is variably defined as “prolonged immobility >5 seconds not reacting to external environment”, or “a player lies motionless on the ice”, or “Lying on ground (>1 s), does not appear to move or react, respond or reply appropriately to the game situation”.

Technology and Personnel

The professional sports organisations involved in this study find the use of video review by medical staff to be an important and useful component of SRC assessment. Such video should be made available to medical staff whenever possible. Ideally however, the video review system should accommodate viewing from multiple camera angles, with facility for playback at varying speeds. This allows sideline medical personnel the opportunity to visualise the impact and subsequent signs, which may only be visible on limited camera angle views. Whether or not additional support from a video technician is required depends on the ease of use of the system employed, and experience and comfort level of the medical staff in the use of the system.

A number of sports provide a distraction-free/private viewing area in which the video assessment can be undertaken. It is unclear whether this results in any significant difference in the reviewers’ performance in the identification of video signs of concussion.

NFL and NHL use ATC as video spotters, who themselves don’t make a diagnosis of concussion, but inform the team medical staff when a potential concussive event has been observed. With the required number of game-day tasks being performed by medical staff, and multiple other distractions associated with caring for team personnel on the sideline, the addition of other observers to help identify potential concussions is useful. NFL (two ATC for each game) and NHL (ATC or physical therapist) use video spotters in addition to sideline medical staff to facilitate identification of head injury events. The NHL also has in-area spotters who watch games live (not on video) to identify visible signs not adequately captured on video. Currently NRL have an informal arrangement where the video technician may also act as a spotter. In WR coaches and team medical staff are encouraged to report suspicious video signs to the independent Match Day Doctor (MDD) for further assessment. In the AFL, whilst there is no formal match day spotter, the video technician is used as an informal spotter used for post-match compliance assessment by AFL Medical Officials. The other sports do not incorporate non-medical-spotters into their game-day regulations.

Whilst this use of video spotters is incorporated into some sports, in most sports an experienced team and/or independent doctor is responsible for reviewing the video, and, in all sports it is ultimately the responsibility of the doctor to make the diagnosis of concussion. The reliability of experienced medical staff, rather than non-medical personnel, in identifying the video signs across many sports needs to be established, as does the reliability of the video signs, either in isolation or as a combination, in predicting a diagnosis of concussion.

Limitations

This study examines use of video technology in the game-day assessment of concussion in six professional sports as of 2018. Most of these sports are situated in Australia and North America, with one sport (WR) played across 119 nations (however not all 119 nations have ready access to video technology). The majority of sporting participants are professional males. These results are not necessarily generalisable across all sports, and may not be applicable to non-professional athletes, in addition to women, adolescents, children or non-contact sports.

The confirmation of a diagnosis of concussion is a clinical decision, and in the absence of a validated biomarker of concussion, there is no doubt that video studies of concussion are at risk of type one error (false positive, in which the video suggests signs of concussion, but a concussion has not occurred), and type two error (false negative, in which there are no video signs of concussion, but clinically concussion is confirmed). Given the absence of a valid biomarker, and the potential for further injury if a concussed individual is not removed from play, it is preferable to err on the side of caution, and accept a higher incidence of type one error.

Recommendations

1. All contact/collision professional sporting codes should provide broadcast video to side-line medical personnel, in real time, preferably with access to multiple camera angles, and facility for playback at variable speeds.
2. There appears to be agreement amongst professional contact sports that the presence of, *Lying motionless, Tonic posturing, Impact seizure, or Motor incoordination* on video review requires removal from the field of play, and whilst many professional sporting bodies recommend permanent removal from play, there is not universal consensus, and further research is required for validation of these signs in professional collision/contact sports.
3. Other aspects that require validation and/or discussion in a future concussion consensus meeting include:
 - i. The applicability of other/additional video signs across all sporting codes as either general or sport-specific visible signs.

- ii. Whether any signs should rise to the level of mandating “no return to play on the day”.
- iii. The utility of specific biomechanical signs.
- iv. The level of education and training required for personnel to review video for presence of signs of concussion.

References

1. Gibbs N, Watsford M. Concussion Incidence and Recurrence in Professional Australian Football Match-Play: A 14-Year Analysis. *J Sports Med (Hindawi Publ Corp)* 2017;2017:2831751. doi: 10.1155/2017/2831751 [published Online First: 2017/08/15]
2. Nathanson JT, Connolly JG, Yuk F, et al. Concussion Incidence in Professional Football: Position-Specific Analysis With Use of a Novel Metric. *Orthop J Sports Med* 2016;4(1):2325967115622621. doi: 10.1177/2325967115622621 [published Online First: 2016/02/06]
3. Patricios J, Fuller GW, Ellenbogen R, 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 doi: 10.1136/bjsports-2016-097441
4. McCrory P, Feddermann-Demont N, Dvorak J, et al. What is the definition of sports-related concussion: a systematic review. *British journal of sports medicine* 2017;51(11):877-87. doi: 10.1136/bjsports-2016-097393 [published Online First: 2017/11/04]
5. Guskiewicz KM, Weaver NL, Padua DA, et al. Epidemiology of concussion in collegiate and high school football players. *The American journal of sports medicine* 2000;28(5):643-50. [published Online First: 2000/10/14]
6. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5(th) international conference on concussion in sport held in Berlin, October 2016. *British journal of sports medicine* 2017;51(11):838-47. doi: 10.1136/bjsports-2017-097699 [published Online First: 2017/04/28]
7. Davis G, Makdissi M. Use of video to facilitate sideline concussion diagnosis and management decision-making. *J Sci Med Sport* 2016;19(11):898-902. doi: 10.1016/j.jsams.2016.02.005 [published Online First: 2016/04/28]
8. 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(10):859-63. doi: 10.1016/j.jsams.2016.02.015 [published Online First: 2016/03/25]
9. Makdissi M, Davis G. Using video analysis for concussion surveillance in Australian football. *J Sci Med Sport* 2016;19(12):958-63. doi: 10.1016/j.jsams.2016.02.014 [published Online First: 2016/03/24]
10. 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* 2017;51(1):64-69. doi: 10.1136/bjsports-2016-096461 [published Online First: 2016/09/03]
11. Fuller GW, Kemp SP, Raftery M. The accuracy and reproducibility of video assessment in the pitch-side management of concussion in elite rugby. *J Sci Med Sport* 2017;20(3):246-49. doi: 10.1016/j.jsams.2016.07.008 [published Online First: 2016/08/22]
12. Tucker R, Raftery M, Kemp S, et al. Risk factors for head injury events in professional rugby union: a video analysis of 464 head injury events to inform proposed injury prevention strategies. *British journal of sports medicine* 2017;51(15):1152-57. doi: 10.1136/bjsports-2017-097895 [published Online First: 2017/06/24]

13. Cross MJ, Tucker R, Raftery M, et al. Tackling concussion in professional rugby union: a case-control study of tackle-based risk factors and recommendations for primary prevention. *British journal of sports medicine* 2017 doi: 10.1136/bjsports-2017-097912 [published Online First: 2017/10/13]
14. Bruce JM, Echemendia RJ, Meeuwisse W, et al. Development of a risk prediction model among professional hockey players with visible signs of concussion. *British journal of sports medicine* 2017 doi: 10.1136/bjsports-2016-097091 [published Online First: 2017/04/06]
15. Echemendia RJ, Bruce JM, Meeuwisse W, et al. Can visible signs predict concussion diagnosis in the National Hockey League? *British journal of sports medicine* 2017 doi: 10.1136/bjsports-2016-097090 [published Online First: 2017/04/06]
16. Hutchison MG, Comper P, Meeuwisse WH, et al. A systematic video analysis of National Hockey League (NHL) concussions, part I: who, when, where and what? *British journal of sports medicine* 2015;49(8):547-51. doi: 10.1136/bjsports-2013-092234
17. Gardner AJ, Howell DR, Levi CR, et al. Evidence of Concussion Signs in National Rugby League Match Play: a Video Review and Validation Study. *Sports Med Open* 2017;3(1):29. doi: 10.1186/s40798-017-0097-9 [published Online First: 2017/08/24]
18. Gardner AJ, Iverson GL, Quinn TN, et al. A preliminary video analysis of concussion in the National Rugby League. *Brain Inj* 2015:1-4. doi: 10.3109/02699052.2015.1034179
19. Gardner AJ, Iverson GL, Stanwell P, et al. A Video Analysis of Use of the New 'Concussion Interchange Rule' in the National Rugby League. *International journal of sports medicine* 2016;37(4):267-73. doi: 10.1055/s-0035-1565203 [published Online First: 2016/02/04]
20. Gardner AJ, Levi CR, Iverson GL. Observational Review and Analysis of Concussion: a Method for Conducting a Standardized Video Analysis of Concussion in Rugby League. *Sports Med Open* 2017;3(1):26. doi: 10.1186/s40798-017-0093-0 [published Online First: 2017/07/16]
21. Gardner AJ, Wojtowicz M, Terry DP, et al. Video and clinical screening of national rugby league players suspected of sustaining concussion. *Brain Inj* 2017;31(13-14):1918-24. doi: 10.1080/02699052.2017.1358399 [published Online First: 2017/09/06]
22. McCrory PR, Berkovic SF. Video analysis of acute motor and convulsive manifestations in sport-related concussion. *Neurology* 2000;54(7):1488-91. [published Online First: 2000/04/06]
23. Hawk-Eye. [Available from: www.hawkeyeinnovations.com accessed 28 May 2018.
24. EVS. [Available from: www.evs.com/en. accessed 28 May 2018.
25. Play MPX. [Available from: <http://www.streamsportsav.com> accessed 28 May 2018.
26. Sport V. [Available from: <http://www.vogosport.com/en/> accessed 28 May 2018.
27. Ellenbogen RG, Batjer H, Cardenas J, et al. National Football League Head, Neck and Spine Committee's Concussion Diagnosis and Management Protocol: 2017-18 season. *British journal of sports medicine* 2018 doi: 10.1136/bjsports-2018-099203 [published Online First: 2018/03/20]
28. Kuhl NO, Yengo-Kahn AM, Burnette H, et al. Sport-related concussive convulsions: a systematic review. *Phys Sportsmed* 2018;46(1):1-7. doi: 10.1080/00913847.2018.1419775 [published Online First: 2017/12/28]

Table 1 Video signs used in each sport

	AFL	World Rugby	NFL	Cricket	NRL	NHL*
Loss of consciousness		Permanent removal	Permanent removal	Permanent removal	Permanent removal	
Loss of responsiveness/ Lying motionless	Requires removal & assessment	Permanent removal			Requires removal & assessment	Requires removal & assessment
Motor incoordination/ Ataxia/ Staggering gait	Permanent removal	Permanent removal	Requires removal & assessment	Permanent removal	Permanent removal	Requires removal & assessment
Stumbles/stagger			Requires removal & assessment	Requires removal & assessment		Requires removal & assessment
No protective action floppy	Permanent removal	Permanent removal	Requires removal & assessment		Permanent removal	Requires removal & assessment
No protective action tonic	Permanent removal	Permanent removal	Requires removal & assessment		Permanent removal	Requires removal & assessment
Cervical hypotonia		Permanent removal	Requires removal & assessment		Permanent removal	
Uncontrolled fall to ground				Permanent removal		Requires removal & assessment
Controlled fall				Requires removal & assessment		
Impact seizure/ convulsion	Permanent removal	Permanent removal	Permanent removal	Permanent removal	Permanent removal	
Tonic posturing	Permanent removal	Permanent removal	Permanent removal	Permanent removal	Permanent removal	
Blank/vacant look	Permanent removal		Requires removal & assessment		Permanent removal	Requires removal & assessment
Dazed	Permanent removal	Permanent removal	Requires removal & assessment		Permanent removal	
Slow to get up			Requires removal & assessment		Requires removal & assessment	Requires removal & assessment
Clutching at head			Requires removal & assessment			Requires removal & assessment
Walking away from pitch disengaged with game		Permanent removal	Requires removal & assessment	Requires removal & assessment		
Disorientation		Permanent removal	Requires removal & assessment		Permanent removal	
Confusion/ behaviour change	Permanent removal	Permanent removal	Requires removal & assessment		Permanent removal	
Facial injury/ fracture			Requires removal & assessment		Requires removal & assessment	

 Permanent removal

 Requires removal & assessment

Note: In addition to above, Removal and Assessment in AFL if **possible** balance disturbance, tonic posturing or impact seizure; World Rugby for any of the above if sign is **possible/sub-threshold**; NRL if **possible motor incoordination**, tonic posturing or impact seizure. * The NHL does not mandate permanent removal based on video alone, but has a protocol on mandatory removal, a standardised assessment and physician clinical decision making regarding diagnosis

Table 2

Definitions used for each sign by each sport

	What signs observable on video review would result in immediate and permanent removal/disqualification of the player from the game (i.e. no go criteria)	What is the definition provided (if any) for each "permanent removal" sign	What signs observable on video review would result in "further assessment" (if no permanent removal signs present) of the player	What is the definition provided (if any) for each "further assessment" sign
AFL	<p>1.No protective action in fall to the ground (tonic or floppy)</p> <p>2.Impact seizure or tonic posturing</p> <p>3.Balance disturbance/ataxia</p> <p>4.Dazed, blank/vacant stare or not their normal selves</p> <p>5.Behavioural change atypical for the player</p>	<p>1. Present if: the player does not use any protective manoeuvres as they fall to the ground (e.g., does not put out arm/s to protect self). Rag doll (appears “floppy”)—loss of muscular control. Tonic posturing (appears “stiff”). Not present if: Any motor response from player in process of falling. The player’s arms are being held, so that they are unable to move to protect themselves. Insufficient time to react—rapid momentum carries the player to ground. Video shows no clear view of player falling.</p> <p>2.Present if: abnormal sustained muscle contraction observed (usually involving one or both arms) so that the limb is held stiff despite the influence of gravity or the position of the player. AND/OR Clonic movements: involuntary contraction and relaxation of muscles, which appears as a jerking movement or “shaking” of the arms, legs or body. Not present if: No clear evidence of tonic posturing or clonic movements. Video shows no clear view of player on ground</p>	<p>1.Loss of Responsiveness</p> <p>2.Possible tonic posturing or impact seizure</p> <p>3.Possible balance disturbance</p>	<p>1.Present if: Lying on ground (>1 s), does not appear to move or react, respond or reply appropriately to the game situation (including teammates, opponents, umpires or medical staff). Not present if: Reacts, responds or replies appropriately. Video shows no clear view of player on ground</p>

		<p>3. Present if: Appears “clumsy”—whether or not assisted off the ground. They may be unsteady on their feet or when trying to get up off the ground, walk in a staggered fashion or look like they have “rubbery legs”. They may be unable to pass or receive ball in a co-ordinated fashion. Not present if: Able to stand/walk/run in usual fashion. If assisted off the ground—does not have any signs of motor incoordination. No attempts to move (e.g., stretched off). Video shows no clear view of player.</p> <p>4. Present if: Player demonstrates no facial expression or emotion in response to the environment. Not present if: Any facial expressions. Video does not show clear view of face.</p>		
World Rugby	<p>1.Convulsion 2.Tonic posturing 3.Ataxia 4.Suspected LOC 5.Clearly dazed</p> <p><i>5 Step approach to video review: Step 1 - Head Impact – 0 seconds Step 2 - Immediate Response – 0-2 seconds Step 3 - Subsequent Response – 2-7 seconds Step 4 - Late Response – Returning to feet Step 5 - Return to play – Return to game participation</i></p>	<p><u>Convulsion</u> Seen in Step 3 – an involuntary sustained contraction of one or more limbs (typically upper limbs) lasting more than a few seconds.</p> <p><u>Tonic posturing</u> Seen in Step 3– an involuntary sustained contraction of one or more limbs (typically upper limbs) lasting a few seconds. The arms are typically held in the air.</p> <p><u>Ataxia</u> Seen in Step2 – if the player remains standing unsteady or unusual gait is visible or if player is on the ground initial movement is delayed Seen in Step3 – the player may be slow to rise, unsteady sitting or rising from the ground or looks to support themselves as they attempt to rise from the ground. Once they have risen the player may be unsteady for the first few steps. Seen in Step4 – Player is unsteady when attempting to return to play or returns to the ground. Player may fail to move immediately to correct position on the field of play. Seen in Step5 – Player moves to avoid participation in game</p> <p><u>Suspected LOC:</u> Seen in Step2 – cervical hypotonia and/or player falls to ground without protective action</p>	<p>Potential tonic posturing. Transient or possible ataxia (1-2 steps) Player lying motionless for < 5 seconds Unclear if cervical hypotonia or protection on falling to ground is present.</p> <p>Possible behaviour change</p> <p>Injury event witnessed with potential to result in a concussive injury</p>	<p>Seen in Step3 – if on the ground the player may move immediately or be motionless for less than 5 seconds. If the player remains standing, they do not participate fully in play immediately</p> <p>Player with head impact event remaining on the ground for more than 60 seconds</p> <p>Player with head impact event, who avoids returning to play or is impaired on returning to play e.g. does not attempt tackle</p> <p>On-field assessment indicated if obvious head impact event and player typically watches play if ongoing OR the player is alert and aware of his environment and the game and is keen to return to play OR the player shows a desire to return to active</p>

		<p>Seen in Step3 – player stays on ground without purposeful movement for > 5 seconds, concern may be shown by other players or match officials</p> <p>Seen in Step4 – Player receives on-field treatment for > 60 seconds</p> <p>Step 5 – Return to play > 60 seconds</p> <p><u>Clearly Dazed:</u> Seen in Step3 – the player may exhibit a blank stare and often shakes his/her head Seen in Step4 – the player is typically slow to respond and may return to the ground Seen in Step5 – player returns to full active participation in play is often delayed</p>		participation in play quickly
NFL	LOC, confusion, amnesia, impact seizure, and tonic posturing.	Loss of consciousness	Confused or dazed appearance, unusual behaviour on field, slow to get up, gross motor instability, or clutching at head.	-
Cricket	LOC, uncontrolled fall to ground, tonic posturing/seizure, loss of balance/co-ordination with inability to stand	LOC (prolonged immobility >5 seconds not reacting to external environment), uncontrolled fall (no protective action taken when falling to the ground), posturing/seizure (self-explanatory), loss of balance/co-ordination with inability to stand (stumble/stagger/loss of balance where player cannot stand on feet as result. This does not include a player simple 'stumbling' after impact but able to regain his balance/control and stand)	NB: These are only preliminary and unverified signs currently undergoing further investigation. Stumble/stagger, walking away from pitch disengaging with the game, controlled fall	stumble/stagger (temporary loss of balance after impact with capacity to regain balance and remain on feet), walking away from pitch disengaging with the game (after impact player walks away from the pitch >2m and does not return, is not reactive to the game situation and environment), controlled fall (falls but braces/protective action taken)
NRL	<p>1. loss of consciousness or suspected loss of consciousness;</p> <p>2. no protective action in fall to ground (tonic or floppy; or cervical hypotonia);</p> <p>3. impact seizure e.g. tonic clonic movements or tonic posturing;</p> <p>4. motor incoordination (eg balance disturbance, clumsiness with upper limbs or in getting up);</p> <p>5. clearly dazed and /or blank/vacant stare or not their normal self (eg no facial expression, no apparent emotion in response to the</p>	NOTE: 'Balance disturbance' is defined as when a Player is unable to stand steadily unassisted or walk normally and steadily without supporting the context of a possible head injury.	<p>1. loss of responsiveness (player lying motionless for >1 second or until support staff arrives);</p> <p>2. possible tonic posturing or impact seizure;</p> <p>3. possible motor incoordination (eg possible balance disturbance, possible clumsiness with upper limbs or in getting up);</p> <p>4. slow to stand : >10 to 15 seconds (1st priority is to ensure that there is no neck injury present*);</p>	<p>1. pre-2018:player motionless for 2-3 seconds or until support staff arrives;</p> <p>2018: >1 sec</p> <p>4. NOTE: *When required, the Player is deemed to have been cleared of a neck injury once the Trainer and/or CMO no longer believes manual in line support of the neck is required.</p>

	environment, reduced conscious state (GCS<15), not responding appropriately to those around him including other players, referees or trainers/medical staff); 6. behavioural change atypical of the player		5. suspected facial fracture; or 6. the Club Medical Officer, or Head (or Yellow) Sports Trainer (following a sideline discussion with the Club Medical Officer), forms a clinical impression that the Player appears to display other signs that a head injury may have occurred following trauma/impact ,	6. can use video to help with their suspicion/clinical impression
NHL	Nil	Nil	1.Loss of consciousness/lying motionless 2.Slow to get up 3.Motor incoordination/balance problems 4.Blank or vacant look 5.Clutching of head after hit	1. A Player lies motionless on the ice or falls to the ice in an unprotected manner (i.e., without stretching out his hands or arms to lessen or minimize his fall) after direct or indirect contact to the head. 2.A player who is hit in the head (directly or indirectly) and takes longer than is typical to get up to his skates. 3.A player who staggers, struggles to get up or skate properly, appears to lose his balance, trips or falls, or stumbles while getting up, trying to get up, or skating following direct or indirect contact to the head. 4.A player who exhibits a blank or vacant look following direct or indirect contact to the head. 5.Player makes a distinct and sustained motion to grab/clutch his head (including face) or helmet with one or both hands after a direct or indirect contact to the head. Exclusion: player fixing or correcting placement of helmet following contact. Note: Grabbing the

				head/face after a high stick blade to the head/face is not considered clutching of the head. #Note: Video review occurs first by AT and then video is sent to Team MD for review
--	--	--	--	--