Situational factors associated with concussion in cricket identified from video analysis

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Abstract
Video analysis of situational factors associated with head impacts and concussion has been completed in several sports, however has yet to be completed in cricket. This study aimed to identify situational factors associated with concussion in elite Australian male and female cricket. Match video of head impacts were coded for player position, impacting object, source of ball, location of impact, and where the ball went after impact. Head impacts were then categorised as either concussion or no concussion based on clinical diagnosis. Data for 197 head impacts included 35 (18%) which were diagnosed as concussion. Head impacts typically occurred to an on-strike batter facing a pace bowler (84%). If the ball stopped or rebounded towards the source, 21% were diagnosed as concussion (13% if the ball deflected away from the source). If impact was to an unprotected head, 38% were diagnosed as concussion (16% if impact was to a helmet). If impact was to the back of the helmet or head, 40% were diagnosed as concussion (11–21% for other areas of the head or helmet). The combination of situational factors most consistent with concussion were impact from ball that hit the back of helmet or head and stopped or rebounded towards the source (PPV 80%, p = 0.002). Consideration of the situational factors of a head impact may improve the speed and accuracy of clinical decision making on whether to remove a player from the field for further assessment, particularly if clinical signs are unclear. Video may be used as a tool to support this process. Improved impact attenuation of cricket helmets, particularly at the back, may reduce the risk of concussion.

Keywords
Brain concussion, video analysis, helmet, clinical management

Date received: 6 April 2020; accepted: 1 July 2020

Introduction
Head injuries typically account for 3–5% of all injuries to high-level cricket players,1–3 however have been reported as high as 25%.1 A ball bowled at pace may arrive at the batter in less than 600 ms following release.4 However, the batter begins to play their shot in the first 150 ms by anticipating where the ball will pitch,5 and therefore has little time to evade an unanticipated short-pitched delivery which will reach them at head-height. Similarly, there is little time to evade a ball off the bat for close-in fielders, the bowler on their follow-through, or off-strike batter.

When a player sustains a head impact, medical staff have the challenge of quickly and accurately...
determining the likelihood of a concussion and whether or not the player needs to be removed from play for further assessment. In addition to looking for clinical signs and symptoms, which may not be immediately apparent, 6 we wanted to know if there are particular situational factors about the head impact itself which could help inform this decision. Secondly, identification of situational factors associated with head impact and concussion in cricket may inform risk reduction strategies (e.g., safety equipment, education, rules) as has been done in other sports. 7–10

Video analysis of situational factors associated with head impacts and concussion in sports commenced in the 1990s in football codes (e.g., Australian Football, 8,11 Rugby Union, 7,8 Rugby League 8,12 and American Football 13,14), and these methods were adapted to other sports in the 2000s, including boxing, 15 soccer, 16 taekwondo, 9 ice hockey, 17,18 and lacrosse. 10 The unique characteristics of each sport, (e.g., equipment, playing situation, player behaviour) necessitate sport-specific research. 19

In cricket, one study by Ranson et al. analysed video for head injuries occurring to elite batters wearing helmets and noted a pattern of impact to the back and side of the helmet for the eight concussions included. 20 This provides important preliminary insight into situational factors associated with concussion in cricket, however further research is needed with a larger sample and including both concussive and non-concussive head impacts. Therefore, the purpose of this study is to review video footage of concussive and non-concussive head impacts in elite Australian cricket players to identify situational factors associated with concussion. This information may improve the speed and accuracy of sideline identification and management of players who sustain a potentially concussive head impact for the benefit of player welfare and the game. A secondary research outcome is information about situational factors related to head impact and concussion in cricket which may inform risk reduction strategies.

**Methods**

Ethics approval was gained from an Institutional Ethics Committee (La Trobe University HEC18494). Data were retrieved from Cricket Australia’s online databases (Athlete Management System and The Cricket Analyst, Fair Play Pty Ltd). Data are recorded in the database in a standardised manner by staff working with state/territory and national cricket teams: clinical records and head impact reports are completed by the team doctor and/or physiotherapist with specific training in sport-related concussion, and; video is catalogued by the data analyst.

A retrospective case series analysis method was applied. Cases (participants) were elite Australian male and female cricket players who sustained a potentially concussive head impact, regardless of injury outcome, during a domestic or international match in the previous five seasons (July 2014 to February 2019). Potentially concussive head impacts (head impacts_PC) were subjectively determined by the team doctor or physiotherapist who witnessed the incident and believed the impact warranted checking on the player and reporting the incident (as per protocol).

Concussion diagnosis was made by an experienced doctor specialising in sports medicine in accordance with the organisation’s concussion protocol and consensus definition. 21 Except in exceptional circumstances (i.e., clear concussion), clinical assessment included a brief on-field assessment, off-field sport concussion assessment tool (SCAT; SCAT3 prior to 2017, and SCAT5 from 2017), 22,23 neurocognitive test (CogSport; Cogstate Ltd.), 24 and routine follow-up over subsequent days. If a doctor was not available at the time of the incident, the highest qualified medical staff available (i.e., physiotherapist) assessed the player as above, and referred the player to the doctor for follow-up and to confirm diagnosis as either concussion or no concussion. Clinical data was used to inform diagnosis, however only concussion diagnosis was included as a dichotomous variable in this study.

The video coding method comprised review of video with reference to a set of fields and descriptors developed by the authors (Table 1). Fields and descriptors were informed by published methods used in other sports; 8–13,15–18 the authors’ knowledge of concussion literature; the authors’ familiarity with concussion in cricket, and; in consideration with what was feasible using standard video from cricket matches. Two authors (DH, AS) independently viewed and coded a subset of 15 videos then discussed uncertainties to clarify and finalise the fields and descriptors. The fields included: player position, impacting object, source of ball, location of impact (Figure 1), and where the ball went after impact (two 180 degree arcs with respect to the source of the ball). A pace bowler was defined as a bowler who delivered the ball at a medium or fast pace and to which the wicket keeper was standing back from the stumps. Clinical signs, such as ‘body language’ or gaze, were not included in the study as the video typically followed the ball rather than remaining on the struck player and the view was often obscured by a helmet.

Video was sought for each head impact_PC recorded during the study period. The availability and quality of video was dependent upon the footage of televised and live-streamed matches. Videos were coded by one author (DH) who was blind to the injury diagnosis.
and each player’s concussion history. Any data points which appeared unclear on the video (due to video quality, angle, or obscured view) were discussed by two authors (DH, AS) and if a particular descriptor could not be determined with certainty it was coded ‘unclear’. Videos could be viewed as many times as required and at any playback speed to confirm details.

Coding and analysis were completed in a custom spreadsheet. Descriptive statistics are reported for all head impact descriptors with 5 of more cases in accordance with ethics requirements. Proportions were calculated with a Wilson 95% confidence interval (CI) and compared using a Chi-squared test. The diagnostic value of head impact descriptors was evaluated using 2 × 2 contingency tables to calculate positive predictive values (PPV) and Fisher’s exact p-values. To account for the multiple comparisons of the 31 descriptors coded (out of a possible 36 specified descriptors), a Bonferroni corrected p-value for statistical significance was determined as 0.002.

Results

During the study period, 458 elite Australian cricketers were collectively exposed to 1,601,368 balls played during a match whilst batting or in the field (Figure 2). Two hundred and seven head impacts were recorded, which translates to an approximate risk of one head impact every 7,736 balls (1,289 overs or approximately 13 days play). The risk of head impact was highest for male players whilst batting (approximately one head impact every 3,732 balls/622 overs/6 days play).

Complete data were available for 197 (95%) head impacts from 130 unique players, to which the following results pertain. Due to the small number of head impacts in female players, male and female data are combined. Mean age at the time of head...
impactsPC was 26±5 years (range 16–38). Concussion was diagnosed in 35 cases (18%, 95% CI 13–24%). Head impactsPC most commonly occurred to on-strike batters (n=173: 88%, 83–92%), of which 28 (16%, 11–22%) were diagnosed as concussion. Fielding, excluding close-in, was the second most common position (n=10; 5%, 3–9%) followed by wicket keeping (n=10; 5%, 2–8%). Collectively, 22 (11%, 7–16%) head impactsPC occurred in the field (all fielding positions, wicket keeper and bowler), of which 7 (32%, 16–53%) were diagnosed as concussion.

The impacting object was most commonly a ball (n=186: 94%, 90–97%), of which 29 (16%, 11–22%) were diagnosed as concussion. Other sources of impact were the ground or another player whilst fielding, and the bat whilst wicket keeping (n=11: 6%, 3–10% collectively as each object n<5), of which six (55%, 28–79%) were diagnosed as concussion.

If the impacting object was a ball, this was most commonly bowled by a pace bowler (n=166: 89%, 84–93%), of which 28 (17%, 12–23%) were diagnosed as concussion. A ball bowled by a spin bowler accounted for 11 incidents (6%, 3–10% of all head impacts; no case diagnosed as concussion). A ball off the bat striking a player ‘on the full’ (without bouncing) accounted for 5 incidents (3%, 1–6% of all head impacts, no case diagnosed as concussion).

The ball deflected away from the source in 120 incidents (65%, 57–71%), of which 15 (13%, 8–20%) were diagnosed as concussion. The ball stopped or rebounded towards the source of the ball in 66 incidents (35%, 29–43%), of which 14 (21%, 13–33%) were diagnosed as concussion (comparison of proportions between deflected and stop or rebounded p=0.154).

Impact most commonly occurred to the helmet (n=176: 89%, 84–93%), of which 28 (16%, 11–22%) were diagnosed as concussion. Impact to an unprotected head occurred in 13 incidents (7%, 4–11%), of which 5 (38%, 18–64%) were diagnosed as concussion (comparison of proportions between helmet and unprotected head p=0.045). Impact to an unprotected neck occurred in 6 incidents (3%, 1–6%) and impact to a neck protector occurred in less than 5 incidents (both concussion n<5).

The positive predictive value of select individual and combined head impactPC descriptors for concussion diagnosis are detailed in Table 2.

**Discussion**

Three key situational factors most consistent with concussion in cricket observed in this study, which may be particularly useful to inform clinical decision-making, are summarised in Figure 3. Observation of one or more of these situational factors may justify removal from play for further assessment at the clinician’s discretion. All other situational factors are less reliable indicators of concussion (or no concussion) and therefore provide little assistance to the clinician.
Impact to the back of the head or helmet was the strongest factor suggestive of concussion (PPV 40\% (95\% CI 20–64), p = 0.028) in this cohort, though not statistically significant. This finding reinforces observations by Ranson et al.\textsuperscript{20} and also the specificity to cricket, as it is not consistent with findings in other sports. For instance, a video study of concussive incidents in lacrosse found the back of the head was least commonly impacted (3\%), with the side of the head most commonly impacted (35\%).\textsuperscript{10} In taekwondo\textsuperscript{9} and ice hockey,\textsuperscript{18} the back of the head was least commonly impacted (9\% and 16\% respectively), and the side of the head most commonly impacted (72\% and 58\% respectively). In junior rugby, 20\% of concussions were due to impact to the back of the head, 70\% to the front, and 0\% to the lateral aspect.\textsuperscript{25} It is not possible to compare the rate of concussion associated with back of the head impacts in these sports without knowledge of the incidence rate of such impacts. The specificity of this finding to cricket may also reflect impact attenuation characteristics of different areas of the cricket helmet, however further research is needed to investigate this further.

The predictive value of impact to the back of the helmet or head was markedly higher if combined with if the ball stopped or rebounded towards the source (PPV 80\% (95\% CI 32–97), p = 0.002). A ball stopping or rebounding back towards the source suggests: i) that the ball trajectory was directed towards the head centre of mass, rather than being a tangential blow,\textsuperscript{26}

Table 2. Positive predictive value (PPV) of select individual and combined head impacts\textsubscript{PC} descriptors for concussion diagnosis in elite cricket players (concussion n ≥ 5).

| Head impact descriptors | PPV (%) (95\% CI) | Fisher exact p-value |
|-------------------------|-------------------|----------------------|
| Impact from ball bowled by pace bowler | 17 (16–18) | 0.323 |
| Impact from ball bowled by spin bowler | 0 | 0.218 |
| Impact from ball off bat on full | 0 | 1.000 |
| Impact from ball that stopped or rebounded towards source | 21 (15–29) | 0.140 |
| Impact from ball that deflected away from source | 13 (9–17) | 0.140 |
| Impact to helmet | 16 (14–18) | 0.057 |
| Impact to unprotected head | 38 (18–64) | 0.058 |
| Impact to front of helmet or head | 11 (5–22) | 0.263 |
| Impact to side of helmet or head | 21 (13–32) | 0.400 |
| Impact to back of helmet or head | 40 (20–64) | 0.028 |
| Impact to faceguard | 15 (8–25) | 0.673 |
| Impact from ball that hit the front of helmet or head and stopped or rebounded towards source | 0 | 0.359 |
| Impact from ball that hit the front of helmet or head and deflected away from source | 14 (7–28) | 1.000 |
| Impact from ball that hit the side of helmet or head and stopped or rebounded towards source | 33 (12–65) | 0.149 |
| Impact from ball that hit the side of helmet or head and deflected away from source | 11 (4–24) | 0.456 |
| Impact from ball that hit the back of helmet or head and stopped or rebounded towards source | 80 (32–97) | 0.002 |
| Impact from ball that hit the back of helmet or head and deflected away from source | 11 (2–49) | 1.000 |
| Impact from ball that hit the faceguard of helmet and stopped or rebounded towards source | 17 (9–31) | 0.797 |
| Impact from ball that hit the faceguard of helmet and deflected away from source | 10 (3–31) | 0.744 |

Figure 3. Summary of key situational factors most consistent with concussion in cricket.
and; ii) that there is a more ‘elastic’ impact with moderate to high coefficient of restitution for the ball-helmet or ball-head system.27 These situational factors both suggest higher magnitude and/or length duration head impact forces, which may explain the observation between ball rebound and concussion. Interestingly, a ball stopping or rebounding towards the source considered independently was not significantly related to concussion diagnosis (PPV 21 (95% CI 15–19), p = 0.140).

Impact with the ground, another player, or the bat were less common yet more severe (approximately 1 in 2 diagnosed as concussion). These situations are associated with potentially higher kinetic energy and impact forces due to the movement of the players and mass speed of the bat. Additionally, impact with the ground or another player whilst fielding would typically be to an unprotected head. Head to ground impacts are potentially more similar to impacts observed in Australian Football, for example, which result in concussion.10 Another intuitively high risk scenario is a ball off the bat on the full impacting a close-in fielder or a bowler post-delivery with little time to react, however no concussions due to this mechanism were noted in the study sample.

Head impacts from a ball bowled by a spin bowler were less common, and none were subsequently diagnosed as concussion. The apparent low risk of concussion from a ball bowled by a spin bowler is consistent with intuition, assuming the relatively lower ball speed and kinetic energy is a factor. However, it is premature to dismiss the risk of concussion from a ball bowled by a spin bowler on the basis of this research at any level of the game.

The perception that impact to the faceguard may be less severe is not supported by this research. The role of the faceguard is to provide a rigid barrier to prevent ball to face impacts. Although faceguards may deform under impact load, they are not intended to provide impact energy attenuation performance to protect the brain, unlike the helmet itself. Therefore, a ball impact with a potentially rigid faceguard may: a) apply an abrupt short duration impact force to the head via the helmet and chin strap, and/or; b) increase the angular acceleration of the head by increasing the moment arm of the ball impact force vector relative to the head centre of mass.

The findings of this study direct attention to the performance of helmets to reduce the risk of concussion. Helmet design and materials, age, and fit are all factors that influence helmet performance.28–30 Efforts are currently being directed to improving the ability of helmets to attenuate impact for the purposes of concussion prevention in other sports, however further research and development is needed.26,28 The intention of the current standard for cricket helmets is to “reduce the frequency and severity of localized injuries to the head . . .” with no specific mention of concussion.31 Future revision of this standard may specifically address the risk of concussion by requiring increased impact energy attenuation. Ranson et al.20 called for improved impact attenuation at the back of the helmet – something we support with this research.

Video is emerging as a valuable tool for concussion management in cricket, as for other sports.32 Firstly, video may assist the real-time identification of head impacts or later review to explain a concussion presentation. The ability to replay events on the sideline allows a medical practitioner to confirm whether or not a head impact occurred. Non-medical personnel such as a video analyst, coach, or third umpire reviewing the video may also act as ‘spotters’ to alert the medical practitioner (and/or relevant person if a medical practitioner is not present at the time). A second role of video may be to assist a medical practitioner to diagnose concussion in a player who sustains a head impact. In some cases, clear signs of concussion may be observed.32 The mechanism and situational factors identified in this study may also assist a practitioner to gauge the likelihood of concussion. The minimum requirement for video is one camera angled down the pitch with footage readily available to review on the sidelines. Current technology makes this a feasible proposition, even for lower-level matches.

A strength of this study is the relatively large sample and inclusion of head impacts without subsequent concussion diagnosis for comparison. However, an inherent limitation is the use of data not originally recorded for research purposes. It is possible that the data may be biased towards more severe head impacts due to: i) the practitioner at the time deeming the impact notable enough to record, and; ii) video only being available for matches, and more often for male and higher-level matches, where the pace of the ball would be greater. Combining data for both male and female players does not allow any possible gender differences to be investigated and, if any differences were present, may have biased results. A further limitation is that the cohort were elite players. At the elite level, pace bowlers bowl faster than lower levels. Players may also have better skill to evade head height balls.

Ball speed would be a valuable addition to future analysis, as would additional camera angles to discern additional situational factors such as the head moving towards or away from the impacting force. Consistent coding of head impacts by video analysts prospectively will allow for further insight (whether strengthening or weakening the findings of this study), extending findings to include more female and youth players, and comparing such groups to see if there are any differences.
Conclusion

Situational factors of a head impact in cricket may assist medical staff to quickly and accurately determine if a concussion is more likely and decide whether to remove a player from the field for further assessment if clinical signs are unclear. Impact to an unprotected head, impact to the back of the head or helmet, and/or impact from a ball that stops or rebounds towards the source (except if impact to the front of the helmet) are key situational factors most consistent with concussion observed in this study. Video may be used as a tool to support the identification of head impacts and to review situational factors in cricket. Improved impact attenuation of cricket helmets, particularly at the back, may reduce the risk of concussion.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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