Journal of Science and Medicine in Sport 23 (2020) 125–133

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

# Concussion incidence and time-loss in Australian football: A systematic review

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ARTICLE INFO

*Article history:*
Received 17 May 2019
Received in revised form 26 August 2019
Accepted 15 October 2019
Available online 25 October 2019

*Keywords:*
Brain injury
Australian rules football
Epidemiology
Time-loss
Return-to-play

ABSTRACT

*Objectives:* Australian football is associated with a risk of concussion. However, despite the extensive and varied nature of literature devoted to this issue, concussion incidence has not been systematically evaluated. To address this, we aimed to conduct a meta-analysis of concussion incidence in Australian football.
*Design:* Systematic review. Prospero registration number: CRD42017064290.
*Methods:* A systematic search of 14 databases using the terms 'concussion', and 'Australian football' (and variations) was used to obtain records that reported concussion incidence per 1000 players hours across age, sex, and level-of-play. Data were grouped based on how time-loss was applied to the concussion definition.
*Results:* Forty-two studies met inclusion criteria. Incidence rates based on a possible time-loss definition per 1000 player hours, ranged from 2.24 to 17.63 at the elite level, and 0.35 to 14.77 at the community/amateur level. Return-to-play details were reported by six studies and only two studies measured head-impacts in real-time. Several limitations were identified with this literature. First, insufficient return-to-play details precluded a meta-analysis of incidence rates. Second, no longitudinal studies across levels-of-play were found. Third, concussion incidence data for junior and female players were notably scarce.
*Conclusions:* There was limited scope to determine concussion burden (i.e., incidence and severity) and only preliminary data for player exposure to head-impacts. To address these limitations, injury surveillance should capture sufficient information to permit comparisons within and across levels-of-play. This will also help determine the influence of interventions aimed at reducing the frequency and severity of concussive-injuries.


## 1. Introduction

Australia's sporting landscape is dominated by Australian football (AF), a fast-paced contact sport that involves frequent collisions through tackling and contested possessions.[1,2] A formal competition, the Victorian Football League (VFL), was established in 1896 and became the Australian Football league (AFL) in 1990. AF is one of the most popular sports in Australia, with 18 elite teams in the AFL, the introduction of the AFL for Women (ALFW) in 2017, and 1,547,915 community-level participants.[3] As a contact sport AF invariably carries a risk of injury.[4–19] Yet despite rules designed to protect a players' head (e.g., no hip and shoulder action resulting in head-impact),[2] concussive injuries[4–20]and head-impacts[21] continue to occur, and are the focus of this review.

Concussion in sport, including AF, is classified as a traumatic brain injury (TBI) induced by biomechanical forces.[22] Its multifaceted nature is highlighted by the definition produced following the 5th International Conference on Concussion in Sport, paraphrased as: (1) head, neck, or face-contact; (2) rapid onset of short-term neurological impairment followed by spontaneous resolution or persistence up to hours; (3) potential neuropathological changes, with acute clinical manifestations likely indicating a functional rather than structural injury; and (4) including a range of clinical signs and symptoms, with or without loss of consciousness, followed by a sequential course of resolution or possible prolonged course.[22] In addition, a recent review highlighted that structural changes following concussion may only be identified with advanced neuroimaging approaches capable of detecting subtle anomalies.[23] This reinforces that our understanding of the

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https://doi.org/10.1016/j.jsams.2019.10.010
1440-2440/

potential effects of concussion, particularly at a cortical level, continues to evolve and requires ongoing exploration.

Recommended sports-related concussion management involves screening a player suspected of sustaining a concussion, immediately removing them from play, and following concussion diagnosis, conducting assessments with resumption of play dependent on individual recovery trajectories.[22] Time-loss (e.g., a minimum 24 h of restricted participation[24] or a missed game[14]) is linked to recovery from concussion and has been considered a marker of concussion severity.[25] For example, return-to-play (RTP) protocols include symptom assessments, and persistent symptoms (i.e., greater than 10 to 14 days in adults and over 4 weeks in children[22]) suggest a delayed recovery that likely involves time-loss. However, limitations need to be considered when applying time-loss as a marker of severity. First, not all players who sustain a concussion will be screened during the game/training in which the concussion occurred, particularly if symptoms only emerge later,[22] thereby potentially reducing the accuracy of the time-loss duration recorded. Second, if only time-loss concussions are tracked, concussions that did not result in greater than 24 h of restricted participation (typically considered a *non-time-loss* injury[24]) or in a missed training session or game, will not be recorded, leading to under-reporting of concussion incidence. Third, players may RTP despite being symptomatic,[22] rendering the relationship between severity and time-loss largely meaningless. Fourth, players are required to be asymptomatic for a greater duration before resuming play compared to previous years,[26] which may foster the possible inaccurate assumption that concussions are becoming increasingly severe because of increased time-loss durations. Finally, the implementation and enforcement of screening and management protocols following self-reported or observed head-impact, depends on the resources and priorities of individual clubs and on player behaviour.[27] Collectively, these sources of variance potentially bias any incidence and time-loss details recorded.

However, despite the limitations with employing a time-loss approach, surveillance protocols often include time-loss in terms of a missed game as a core criterion to determine concussion/injury incidence.[4–17,28] This occurs even though the *diagnosis* of a concussion does not mandate any time-loss. For example, from 1992 the AFL introduced mandatory reporting of injuries, and in 1996 commenced annual AFL Injury Reports (AFL-IRs); from 1997 onwards, the AFL have defined an injury, including concussions, as an '*injury or medical condition which causes a player to miss a match*'.[4–17] This is despite an assessment by the AFL on the effect of rule changes on AFL injuries highlighting how the time-loss injury definition is '*. . . less appropriate'* for monitoring concussions, as it under-reports concussion incidence.[29] Consequently, although time-loss details can contribute to our understanding of the impact of a concussive injury, this is only possible if: (1) a player is appropriately managed (i.e., symptomatic presentations are treated in accordance with time-loss protocols); and (2) all time-loss details, including any periods of non-participation that do not necessarily result in a missed game, are recorded.

By extension, when considering the risk-profile for concussion, facilitating direct comparisons both within and between different levels-of-play and across sports, requires that incidence data be reported in a comparable format. Presenting data per 1000 player hours accommodates match duration and is considered an accurate measure of concussion/injury incidence.[25,28,30] In addition, assessment of injury recovery via time-loss (i.e., time-to-RTP), coupled with incidence per 1000 player hours, reveals *injury burden* in terms of lost time per 1000 player hours. This is a useful metric when considering the risk-profile of specific injuries both within and across sports and is in-line with healthcare research that considers the burden of disease by combining incidence rates and time lost.[25] However, as there is no consensus on guidelines for reporting injuries –including concussion– injury surveillance approaches typically fail to report both the incidence in a comparable format and time-loss specifics.[25] These limitations independently and collectively undermine the accuracy of concussion tracking approaches and may lead to under-reporting of concussion burden. Care should be taken not to discount those injuries that resolve without time-loss or with less than 24 h of time-loss, and to avoid concluding that an absence of time-loss indicates an injury of reduced severity.

As demonstrated, sustaining a concussion clearly does not require that time-loss occur, however, whether a concussion is included in incidence rates often, but not always, depends on this criterion. It therefore forms a critical component of data collection practices that needs to be considered when analysing results and to permit accurate comparisons of trends. For the purpose of this review, injury/concussion definitions are categorised as follows: (1) a *time-loss* definition mandated that a player miss a game or training session; and (2) a *possible time-loss* definition either did not mention time-loss, or specified that *time-loss,* in terms of a missed game/training, or interference with any degree of participation, was a sufficient –but not mandated– criterion. The *possible time-loss* definition also incorporates *non-time-loss*; this accommodates time-loss that may include only game-day time-loss or time-loss of less than 24 h.

The recently updated position statement on concussion in sport in Australia, collaboratively produced by the Australian Institute of Sport, Australian Medical Association, Australasian College of Sport and Exercise Physicians, and Sports Medicine Australia,[31] reflects the scope and complexity of concussive injuries. Specific to sport-related concussion incidence it was noted that data in Australia is limited, with difficulties in data collection including symptom recognition, and athletes under-reporting and failing to consult medical professionals.[31] Inadequate knowledge of concussion incidence and time-loss suggests methods of concussion surveillance need to be addressed. Yet while sports-related concussive injuries are a growing public health concern in Australia[31] and internationally,[32] a systematic review of concussion incidence and time-loss literature in AF has not been conducted. Furthermore, it is unclear how rates compare across levels-of-play and with other sports. This is particularly important for concussion management and prevention as failing to capture sufficient data will prevent us from drawing accurate conclusions about the effectiveness of protocols designed to decrease the rate and severity of concussions in AF.

Therefore, this is a timely systematic review that primarily aimed to determine the incidence of concussion and time-loss specifics in AF and compare results across levels-of-play. A secondary aim was to explore head-impact exposure rates (e.g., sub-concussive impacts) in AF. Findings are discussed with regard to methodological approaches designed to track concussion incidence, particularly the limitations identified with the incidence inclusion criteria applied, and recommendations are made for future concussion surveillance practices in AF.

## 2. Methods

A protocol that incorporated concussion incidence was registered with PROSPERO (registration number: CRD42017064290) and PRISMA guidelines were followed. Studies with participants who were concussed or exposed to head-impacts, including sub-concussive impacts, while playing AF were identified via an electronic search of 14 databases on April 8, 2018, using variations of the terms 'concussion' AND 'Australian football' (see Supplementary Table 1 for the databases and PubMed search strategy).

Although not always peer-reviewed, AFL-IRs provide elite-level concussion data and were sourced using Google. Author CM performed all searches.

Articles were included if they: (a) were peer reviewed (unless an AFL-IR), English language journal articles, published or in press, up to April 8, 2018; and (b) reported head-impact (including sub-concussive) exposure rate, or concussion incidence per 1000 player/game/training hours (or provided data to enable conversion), in participants who played AF, regardless of age, sex, or level-of-play. Following removal of duplicates, author CM screened records on title and abstract to determine full-text articles for review (see Supplementary Figure 1 for the PRISMA flowchart). Authors GC and CD independently screened 20% on title and abstract to ensure consistency with the full-text articles selected. CM and GC independently screened the selected 264 full-text articles to determine the final selection of 42 articles.[4–21,33–56]

The following data were extracted by authors CM and GC: (1) study aim; (2) level-of-play; (3) participant characteristics; (4) concussion definition and diagnosis; (5) concussion incidence rate (or conversion data); (6) return-to-play/time-loss details; (7) mechanisms of injury; (8) concussion injury ranking; and, where applicable, (9) head-impact exposure rate. Terminology used within each article was maintained for data extraction. Authors CM and GC independently assessed risk-of-bias using a 10-item questionnaire previously used to assess sports injury data.[57]

As this review focused on concussion incidence per 1000 player hours, the following equations were applied in-line with previous meta-analyses:[28,30]

$$\text{Concussion incidence} = \left(\frac{\text{Number of concussions}}{\text{Number of matches} \times \text{Number of players} \times \text{Match durationhours}}\right) \times 1000$$

OR

$$\text{Concussion incidence} = \left(\frac{\text{Number of concussions}}{\text{Player hours}}\right) \times 1000$$

Despite data in a standardised format, individual findings could not be combined as time-loss details were not provided; this rendered the data too heterogenous. For example, studies that used a *possible time-loss* definition potentially combined concussions that did and did not result in time-loss into one incidence rate. That is, even where a definition does not mandate time-loss, it does not negate that time-loss may have occurred. Indeed, nine studies that did not mention any time-loss details in the definition, noted within the findings that games or training at the concussive injury level[20,40,49,51,53–55]or injury-category level[35,37] were either missed or may have been missed. As such, the criteria used to quantify concussions across the included studies have nuances that are unaccounted for and prevented meaningful comparisons from being made with a meta-analytic approach; a narrative synthesis was therefore conducted.

## 3. Results

The final selection of 42 articles included 16 AFL-IRs;[4–19] 18 articles on injury surveillance;[33–50] six empirical articles that reported concussion incidence,[20,51–55] and two that reported head-impact exposure. [21,56] All players participated in AF in Australia. From a total possible score of 10, where 10 indicates a low risk-of-bias, the overall risk-of-bias average (excluding head-impact exposure studies) was 7.7. See Supplementary Table 2 for individual study scores. As only two studies explored real-time head-impact kinematics, results are presented in Supplementary Table 7.

The protocol for concussion diagnosis included diagnosis or verification by club medical staff,[20,33–36,38–40,50–55] with data entry performed by a club doctor,[38,39,41] sports trainer,[37,41,46] physiotherapist,[41,48] player self-report,[42] or by a nominated team parent/teacher/coach/manager/staff member/trained volunteer[37,43–47,50] Mechanism of injury details were predominantly reported at the total[47,35,37,41,43,45] or broad injury-category level,[46,50] rather than the specific concussive-injury level.[53,54]

Focusing on non-AFL-IRs, Table 1 outlines incidence rates per 1000 player hours, confidence intervals, and time-loss details reported in concussion definitions, by level-of-play. All studies included only male participants; one junior-level study included 17 female participants,[37] however injuries were reported at the total rather than sex-specific level. A time-loss definition was used by only one study.[50] With the exception of amateur-level data collected in 1993,[39] rates at the elite-level were consistently greater than at the community/amateur-level. However, there were no other consistent trends based on level-of-play or definition (see Supplementary Table 3 for additional data).

Several reporting formats were used in the AFL-IRs. The majority reported a time-loss injury definition;[4–17] two did not include any definition[18,19] but presumably used a time-loss definition, while new concussions per club per season and concussion prevalence (i.e., missed games per club per season) were consistently recorded.[4–19] In the 2016 AFL-IR,[19] concussion incidence from 2011 to 2016 was reported as the number of concussions per 1000 player hours of exposure, regardless of matches missed. From 1992 to 2016, time-loss concussion incidence per 1000 player hours of match exposure were calculated using conversion details provided in the 2012 AFL-IR[15] (see Supplementary Tables 4, 5, and 6 for AFL concussion data).

As detailed in Table 2, the difficulties in comparing incidence rates as a function of the time-loss definition applied are demonstrated by data from the AFL-IRs and individual studies that assessed elite players during the same season(s). For example, a 14-year surveillance of one AFL club that did not require time-loss for a concussion to be included, generated an incidence rate of 17.63.[49] As no concussion resulted in a missed match[49] applying a missed match time-loss definition would have produced an incidence rate of zero. The comparable time-loss incidence rate from the AFL-IRs was 0.59.[4–16] As shown, possible time-loss figures were between 5.33–41.97 times higher than time-loss incidence across all adult elite-level comparisons.

When considering the injury-risk profile of a sport, injury burden can be demonstrated by creating a risk matrix that considers the relationship between severity (i.e., number of days lost) and incidence (i.e., per 1000 player hours).[25] In the current review, RTP details at the concussive-injury level were only reported by six[20,40,49,51,53,54] of the 42 studies. One study noted that while 88% of players left the field immediately post-concussion, 47% RTP that game,[54] with further time-loss details reported according to the injury-category of 'head injuries', not concussion. A median 4.8 days were lost to concussion across elite, junior-elite, and community-level competitions, and while no significant differences in average RTP time-frames across levels were reported,[20] level-specific RTP details were not provided. Only four studies reported days or matches lost at the group-[40] or player-level[49,51,53] Specifically, 16 competition matches were missed from 70 concussions at the elite-level,[40] while among 23 elite-level players who sustained a concussion, 10 returned the day-of-injury, 6 returned by day-7, and 7 returned by day-14.[51] A video analysis of 138 elite-level concussions noted that 11 resulted in one missed game.[53] In contrast, another study at the elite-level found that from 140 concussions, no games were missed.[49] Given the either absent or incomplete reporting of time-loss details across the majority of studies, a meaningful interpretation of concussion burden in the AF, incorporating both incidence and severity, was not possible.

**Table 1**
Concussion incidence rate per 1000 h and time-loss details.

| Reference | Level-of-play<br>Season(s) | Players, n Player hours, n | Injuries, n Concussions, n | Concussion incidence per 1000 h (95% CI) | Time-loss details provided in the definition |
|---|---|---|---|---|---|
| **Time-loss** | | | | | |
| Lathlean et al.[50] | Junior-elite<br>2014 | 562<br>32,043.01[d] MT | 1192<br>6 | 0.19[a] (0.08-0.39) | Player must have missed a full training session or game. |
| **Possible time-loss** | | | | | |
| Sali et al.[34] | VFL<br>1979 | 449<br>11,040 | 531<br>30 | 2.72[b] (1.87-3.83) | Includes possible time-loss from exclusion from game-play, interference in training, or a missed game. |
| Shawdon et al.[39] | Amateur: adult<br>1993 | 80<br>541.67[d] | 52<br>8 | 14.77[a] (6.86-28.05) | Includes possible time-loss from a missed game. |
| Dicker et al.[36] | VFL<br>1979, 1980, 1982 | 1287<br>29,568[d] | 1408<br>74 | 2.50[b] (1.98-3.12) | Includes possible time-loss from interference with subsequent play and training. |
| Seward et al.[38] | AFL<br>1992 | NR<br>15,177[d] | All injuries: 941<br>34 | 2.24[a] (1.58-3.10) | Includes possible time-loss from a missed game or training. |
| Finch et al.[42] | Community: junior/adult<br>1997-1998 | 547<br>36,218.91[d] MT | AF specific: 728<br>AF specific: 48 | 0.50[a] (0.30-0.77) | Includes possible time-loss from reduction in the amount or level of participation. |
| Gabbe et al.[41] | Amateur: adult<br>1999 | 320<br>12,867.64[d] MT | 350<br>11 | 0.85[a] (0.45-1.49) | Includes possible time-loss from missed game-time or training session(s). |
| Grimmer et al.[43] | Community: junior<br>2000 | Total: 697; UD<br>U13: 87; 4629.63[d]<br>U15: 183; 7034.48[d] | Total: 234; 6<br>U13: 50; 2<br>U15: 102; 4 | Total: UD<br>U13: 0.43[a] (0.07-1.43)<br>U15: 0.57[a] (0.18-1.37) | Includes possible time-loss from significant interference with enjoyment of sport. |
| Braham et al.[44] | Community: adult<br>2001 | 294<br>14,230.77[d] | HNO: 37<br>7 | 0.49[a,c] (0.22-0.97)<br>(based on HNO injury incidence) | Time-loss not mentioned. |
| Braham et al.[45] | Community: adult<br>2001 | 301<br>17,355.37[d] MT | 210<br>9 | 0.52[a,c] (0.25-0.95)<br>(based on overall injury incidence) | Includes possible time-loss from an incomplete or missed training, session, or game. |
| Twomey et al.[47] | Community: 18<br>2007-2008 | NR<br>8979.59[d] | 352<br>14 | 1.56[a] (0.89-2.55) | Includes possible time-loss from missed game-time. Time-loss injury severity noted. |
| Colby et al.[48] | AFL/WAFL<br>2012 | Total: 46; 30,459 MT<br>Pre-season: NR; 1405.8 MT<br>In-season: NR; 1700.4 MT | 297; 13<br>110; 4<br>187; 9 | 4.19 (2.33-6.98)<br>2.85 (0.90-6.86)<br>5.29 (2.58-9.71) | Includes possible time-loss from modified participation, or a missed game(s) or training(s). Time-loss injury severity noted. |

| | | | | | |
|---|---|---|---|---|---|
| Ferguson et al.[33] | NR (published in 1965, with injuries from 'over 18 years') | ~2600 (reported as an estimate)<br>13,000 | 792<br>21 | 1.62 (1.03-2.43) | Time-loss not mentioned. |
| Hoy et al.[35] | Community: seniors<br>1981 | 449<br>2752 | 531<br>30 | 3.11[c] (1.45-5.91) | Time-loss not mentioned. |
| Orchard et al.[40] | AFL<br>1994-1997 | 86<br>5895.27[c] | 2308<br>70 | 11.87[a] (9.33-14.91) | Time-loss not mentioned[e] |
| McMahon et al.[37] | Community: children and adolescents<br>1992 | Total: 1253; 30,459<br>Under 15: 565; 15,024 | 246; 15<br>147; 12 | 0.49[a] (0.29-0.79)<br>0.80[a] (3.47-12.51) | Includes possible time-loss from interference with normal functioning during training, game, school, or leisure. |
| McCrory et al.[51] | AFL<br>20-week season | 303<br>6969.70[d] | NA<br>23 | 3.30 (2.14-4.87) | Time-loss not mentioned[e] |
| McCrory et al.[52] | AFL<br>1995-1997 | 303<br>7187.50[d] | NA<br>23[f] | 3.20 (2.08-4.73) | Time-loss not mentioned. |
| Makdissi et al.[53] | AFL<br>2000-2003 | 158<br>24,642.86[d] | NA<br>199 (138 cases analysed) | 5.60 (4.72-6.60) | Time-loss not mentioned[e] |
| Makdissi et al.[20] | Elite, elite-junior, community<br>2001-2004 | Elite: 675; 20,571.43[d]<br>Elite-junior: 272; 4615.38[d]<br>Community: 68; 3125[d] | NA; 72<br>NA: 6<br>NA; 10 | 3.50 (2.76-4.38)<br>1.30 (0.53-2.70)<br>3.20 (1.63-5.70) | Time-loss not mentioned[e] |
| Romiti et al.[46] | Community: junior<br>2004 | NR<br>39,722.22[d] MT | 715<br>14 | 0.35[a] (0.20-0.58) | Time-loss not mentioned. |
| Fortington et al.[54] | Community: adults<br>2007 or 2008 | 1564<br>68,094.24[d] MT | 143<br>34 | 0.50 (0.35-0.70) | Includes possible time-loss from missed game-play[e] |
| Makdissi et al.[55] | AFL<br>2011 | 764<br>9425.29[d] | NA<br>82[f] | 8.70 (6.96-10.74) | Includes possible time-loss from missed game-play. |
| Gibbs et al.[49] | AFL<br>2000-2013 | Total: 116; 7972.02<br>Regular: 226; 7373.52<br>Finals: 116; 598.5 | NA; 140<br>NA; 130<br>NA; 10 | 17.56 (14.83-20.66)<br>17.63 (14.79-20.86)<br>16.71 (8.49-29.78) | Time-loss not mentioned[e] |

*Note:* All Confidence Intervals were estimated using the exact Mid-P method.[58] Article-specific terms are reported (i.e., community or amateur). ≥: Greater than or equal to. HNO: Head/neck/orofacial. HNF: Head/neck/face. NA: Not applicable (applies to studies that only focused on concussive injuries). MT: Match and training hours. NR: Not reported. UD: Unable to determine. VFL: Victorian Football League. WAFL: Western Australian Football League.

[a] Incidence calculated (see Supplementary Table 3).

[b] Incidence calculated using person-risk hours.

[c] Data from the same sample.

[d] Player hours calculated.

[e] Time-loss or possible time-loss noted in results.

[f] Concussions reported from video analysis retrieved from the AFL Medical Officers (AFLMO) Injury Survey Database.

**Table 2**
Incidence rate comparisons based on time-loss at the elite and junior-elite levels.

| Level-of-play Season(s)[a] | Average concussion incidence: new concussions per club per season (time-loss)[b] | Concussion incidence: per 1000 player hours of match exposure (time-loss) | Average concussion incidence: per club per season (possible-time-loss) | Average concussion incidence: per 1000 player hours (possible time-loss) |
|---|---|---|---|---|
| Elite | | | | |
| 1992 | 1.3[4] | 1.08[c] | – | 2.24[38, d] |
| 1994–1997 | 0.80[4] | 0.67[c] | – | 11.87[40, d] |
| 1995–1997 | 0.80[4] | 0.67[c] | – | 3.2[52] |
| 2000–2003 | 0.58[4–6] | 0.48[c] | – | 5.6[53] |
| 2000–2013 | 0.59[4–16] | 0.49[c] | – | 17.63[49] |
| 2001–2004 | 0.5[4–7] | 0.42[c] | – | 3.5[20] |
| 2011 | 1.1[14] | 0.92[c] | 7.7[19] | 8.0[19] |
| 2012 | 1.0[15] | 0.83[c] | 9.1[19] | 9.4[19]; 4.19[48] |
| Elite-junior | | | | |
| 2001–2003 | – | – | – | 1.3[20] |
| 2014 | – | 0.19[50] | | – |

Note. – no data.
[a] AFL club averages for injury statistics are scaled to 40 players over 22 matches.
[b] Incidence calculated using data from AFL-IRs.
[c] Incidence calculated using 'approximate' player hours and conversion details provided in the AFL-IR for season 2012[15]: $\left(\frac{\text{concussion incidence}}{1200}\right) \times 1000$.
[d] Incidence calculated (see Supplementary Table 3).

## 4. Discussion

This article presents a comprehensive review of concussion incidence, time-loss, and head-impact exposure involving Australian footballers. Failing to report time-loss details and variations in the concussion/injury definition applied, made it particularly challenging to compare incidence and rendered a meta-analytic approach unsuitable. Similar to findings in Rugby Union,[28] incidence rates per 1000 player hours differed across and within levels-of-play. A possible time-loss definition produced incidence from 0.35[46] to 0.80[37] at the junior community-level; from 0.49[44] to 14.77[39] at the adult community-level; and from 2.24[38] to 17.63[49] at the elite-level. In addition, only seven studies[41,42,44–46,48,50,54] reported a combined training and match incidence rate, and only two[44,54] reported the number of concussions sustained during training (i.e., no concussions occurred). While this may indicate that concussions occur infrequently in AF training sessions, explicit reporting of the concussion location and training hours are required to accurately determine incidence and concussion risk. It is clear, however, that incidence rates were a direct function of how the time-loss criterion were applied. Thus, in order to permit generalisations of concussion trends specific to each level-of-play and promote more meaningful interpretations of the data generated (e.g., promote targeted concussion prevention), studies and surveillance reports should aim to record *all* concussions, alongside mechanism of injury and RTP time-frames.

At the elite-level, considerable differences were found between time-loss and possible-time-loss incidence rates across the same season(s). For example, when applying a time-loss definition for concussion incidence per 1000 player hours of match exposure in the AFL, the rate was 0.92 for the 2011 season. In contrast, using a possible-time-loss definition with the same metric generated a rate of 8.70.[55] Similarly, across the 1994 to 1997 seasons, the time-loss incidence rate was 0.67, but the possible-time-loss rate was 11.87.[40] In both instances, the *definition* applied for the higher incidences did not mention time-loss, yet one study noted incidence was recorded '*...regardless of matches missed*',[55] and the other reported 16 competition matches were missed due to concussion.[40] This indicates that the majority of concussions did not result in a missed match. The lack of missed matches is potentially due to the time between AFL matches, which is typically from 6 to 8 days. It is also possible that players were RTP despite being symptomatic, which highlights the possible failure to adhere to mandated head-impact protocols. This was demonstrated by a recent review focused on European football (soccer) that revealed during the 2016 Union of European Football Association Football Championship, 72.4% of elite male soccer players suspected of sustaining a concussion were not medically assessed in accordance with international recommendations.[59]

A change in incidence rate can only be interpreted as meaningful if the baseline data is complete. Therefore, failing to effectively manage head-impacts and record details about each concussion across levels-of-play will render assessment of concussion interventions largely incomplete from a clinical perspective. Complete recording in the first instance, coupled with complete reporting of concussion incidence in the public domain, will ensure that the decision process around whether to participate/continuing participating, incorporates an accurate understanding of concussion risk. The inclusion of concussion incidence rates (but not any other injury rates) reported per 1000 player hours, regardless of any matches missed, in the 2016 AFL Injury Report,[19] reflects an attempt to address the issues present when using only a time-loss definition for concussions. In-line with surveillance reporting in other sports,[24] a more accurate approach for AF would be to record how long players are restricted for, with regard to participating in sports-related activities. This will help reveal player-specific RTP trajectories that better depict the concussion landscape in AF.

Large samples over more than one season at the elite-level are anticipated, as AFL player contracts include consent for the use of player injury data for research purposes.[13–17] However, while comparable sample sizes were found at the community/amateur level,[37,42,43,54] incidence rates at this level were typically lower than at the elite-level. This could reflect the limited ability to capture complete data. For example, a recent survey revealed that AF coaches and sports trainers at the community-level experienced difficulty implementing concussion guidelines due to issues such as parents and players disputing or resisting the decisions made.[27] The differences could also reflect the services available; while players at the elite-level have access to medical personnel to diagnose a concussion and video review to ensure head-impact incidents are followed-up, at the community-level, the onus is often on the player to self-report a head-impact before concussion protocols are implemented. However, despite these advantages at the elite level, it is important to note that head-impacts may go unreported. This was demonstrated in American Football, where the likelihood of reporting a concussion to a medical professional was only 47%, compared to 80% for other injuries.[60] This further highlights that concussions are systematically under-reported across sports.

The possible limited capacity to identify all concussions also potentially explains why only two studies[54,55] (one of which included video analysis at the elite-level[55]) reported mechanisms of concussive-injury. Insufficient reporting of mechanisms of injury were similarly reported in a review that considered injury prevention in community AF.[61] Finch et al. found that a combined mechanism of injury for all injuries was predominantly reported, as opposed to providing details for specific injury categories or body regions.[61] Tracking incident-specifics will help identify trends and potentially promote level-specific injury prevention approaches that improve player safety (e.g., by isolating modifiable factors that contribute to head-impacts).

Two player groups, female and junior athletes, were inadequately represented in the literature. While the lack of data involving female AF players is striking, it is consistent with research involving female athletes in contact sports.[62] Despite only recent advancements in terms of professionalism of women's AF, women have competed in formal competitions nation-wide for decades, with the earliest recorded league established in 1992. In 2017, 463,364 females participated in AF, alongside a 76% increase in the number of female teams in Australia.[3] Yet female AF players were only included in one study that focused on injury incidence[37] and one focused on head-impact exposure.[21] In addition, the majority of studies referred to a specific league or level-of-play without mentioning gender;[33–36,38–40,43–52] the inference being that a study on AF could only include males. Given the number of female footballers is likely to increase as the AFLW expands, a concerted effort must be made to track these female athletes to ensure appropriate concussion protocols are implemented and long-term consequences are managed, or indeed prevented. This is particularly important given a recent review revealed that females competing in soccer and ice-hockey were at a greater risk of concussion compared to male players.[62]

The lack of data involving younger players is also notable. However, while data for young players can be captured through participation in Auskick, which is AF for children that applies modified rules which change as children age,[63] evidence highlights that recording injury information, particularly at the community-level, is challenging. Findings from a recent survey revealed parents of community-level junior AF players often have difficulty determining when a child has sustained a concussion.[64] In addition, the evaluation of an implemented injury surveillance system found that of the 78 AF clubs involved, only 9% implemented the system for a second season, with the majority (69%) not progressing beyond being advised about, or trained in, how to use the system.[65] While the studies in the current review used various reporting methods, concussions at the community-level were often recorded by club volunteers. This suggests that ongoing attempts to improve surveillance will require an adaptable reporting approach developed in consultation with players and club/team stakeholders. In addition, given the community setting of Auskick, which had 200, 138 participants in 2017,[3] hospital-based data is more likely to capture children injured at this level. However, relying on this approach will likely fail to capture details such as mechanism of injury and time-loss. Indeed, a prospective study that recorded injury details from under-10 s participating in conventional AF or with modified rules (i.e., Vickick), did not report injury-specific time-loss details.[37]

Unfortunately, there were no longitudinal studies, or studies that permitted sufficient comparisons, involving AF players as they progressed through different level-of-play. Thus, there are significant knowledge gaps regarding concussion rates over developmental periods. Identifying the extent of the issue of concussion within AF is a necessary first step within the *sequence of prevention* framework.[66] The recently updated version of this framework accommodates the *context* of sports injuries and promotes preventative measures by incorporating factors at the individual, socio-cultural, and environmental or policy level. This type of socioecological model has already been considered a viable approach to preventing and managing sports-related concussion.[32] As such, implementing longitudinal assessments in AF will help ensure head-impact exposure is considered in relation to the acute and long-term consequences of concussive injuries, and with regard to contextual factors that influence the ability to capture concussion incidence and implement concussion management protocols. As a result, this approach will potentially shape public health initiatives focused on head-impact education, prevention, and treatment.

The minimal exploration of head-impact exposure in AF[21,56] is unsurprising. Translating head-impact data to represent meaningful clinical outcomes or physiological changes is in its infancy, with recent findings failing to establish a link between biomechanical input and manifestations of concussion in American Football players.[67] Although in its early stages, objectively capturing real-time head-impact data, particularly in relation to player-specific outcomes, represents an important avenue for future research.

Finally, while there are AFL sanctioned male and female competitions in other countries including South Africa, Germany, and the United States, there were no studies conducted outside of Australia. As AF is still an emerging sport in these countries, there is a potential risk of inexperienced coaching that may inadvertently influence the risk of concussion for players. To help determine if geographical trends exist and to permit comparison of AF-specific concussion management protocols, it is imperative that concussion incidence and other injury trends are captured from international AF competitions.

While an extensive search across 14 databases using pre-defined criteria was conducted and the use of broad search terms, particularly 'injury', reduced the likelihood of missing relevant studies, there are limitations. While the overall risk-of-bias was low, studies that did not report concussion incidence in a standardised format, or provide conversion data, were excluded, which may have impacted the results. Nonetheless, even with concussion incidence rates in relation to player hours, we were still unable to conduct a meta-analysis due to the heterogeneity of the data, and therefore relied on a narrative synthesis. In addition, as the majority of studies were surveillance-based, follow-ups were infrequent. However, these studies provide a foundation for establishing the extent and nature of concussive injuries in AF, which is a necessary step toward isolating preventative measures. Employing etiological study designs in future research will promote follow-ups over extended periods and produce comparable data; this approach will help determine incidence rates and identify potentially modifiable contextual factors that contribute to the issue of concussion.

## 5. Conclusions

Current data collection practices fail to capture all concussions and do not include enough information about the concussions recorded, most notably RTP and mechanism of injury details. This has contributed to significant knowledge gaps regarding the incidence and nature of concussive impacts in AF across levels-of-play and has severely restricted the ability to: (1) make informed decisions about future participation in AF; (2) permit comparisons of risk across sports; and (3) monitor the effectiveness of concussion interventions and management protocols. We propose that future research efforts, including injury surveillance approaches and empirical studies, address the following: (1) promote accurate recording of all concussions and related details, including number of players, number of matches/training, mechanism of injury, and any time-loss (i.e., hours, days etc.) from sports-related activity; (2) explore the contextual factors that contribute to the incidence of concussive injuries in AF and influence RTP management; (3) determine if concussive injuries in AF are the result of AF-specific concussive mechanisms that may be amenable to intervention; (4) develop technologies that accurately capture head-impact kinematics in real-time, determine head-impact exposure rates, and promote objective RTP protocols; and (5) quantify the risk and severity of brain injury in AF by tracking these injuries over extended periods. Collectively, these approaches will help promote appropriate injury management and improve player outcomes.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Acknowledgements

The authors thank the reviewers for their feedback and insightful comments.

## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jsams.2019.10.010.

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