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Original research

The impact of concussion on subsequent injury risk in elite junior Australian football athletes

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ABSTRACT

Objectives: Concussion increases injury risk. However, this has not been investigated in junior Australian football and it is unknown whether the location, severity, and mechanism of subsequent injuries differ after concussion vs. non-concussion injury.
Design: Prospective cohort.
Methods: 1455 elite adolescent male Australian footballers were tracked across seven seasons to determine whether subsequent injury risk was greater after concussion compared to non-concussion index injury using multilevel survival analysis. Mixed-effects logistic regression compared location and mechanism. Mixed-effects Poisson regression compared severity.
Results: Of 1455 athletes, 632 were injured and included in subsequent-injury analysis. There were no differences in injury incidence after a concussion compared to upper- (hazard ratio = 1.0, 0.6 to 1.9, P = 0.892; *trivial effect*) and lower (hazard ratio = 1.1, 0.6 to 1.9, P = 0.810; *trivial effect*) index injury, or in location. Subsequent injuries were more likely to be contact-based after a non-concussion injury than concussion (odds ratio = 4.6, 1.3 to 16.0; P = 0.017; *large effect*). There was no difference in subsequent injury severity after lower- (3.4 ± 3.0 missed matches; incidence rate ratio = 1.4, 0.9 to 2.1; P ≤ 0.117; *small effect*) and upper-limb injuries (3.4 ± 3.1 missed matches; incidence rate ratio = 1.4, 0.9 to 2.2; P = 0.189; *small effect*) compared to concussion (2.4 ± 2.0 missed matches).
Conclusions: Subsequent injury risk, severity, and location in junior Australian football are similar following concussion compared to non-concussion index injuries, although contact injuries are less likely.

Practical implications

- The risk, anatomical location, and severity of subsequent injury in junior AF are not different following concussion compared to non-concussion index injuries.
- Contact injuries are less likely after a concussion index injury.
- Concussion injuries require different rehabilitation strategies to non-concussion injuries to ensure athletes are prepared for match play.

1. Introduction

Australian Rules Football (AF) is a contact sport that has a high risk of injury at junior and senior levels (24.3[1] and 41.7[2] injuries per standardised club per season, respectively). Injuries impact player success and career longevity in team sports, whilst having detrimental effects on team success.[3] Concussions are one of the most common injuries in AF (6 concussions per 1000 h played).[2] Classified as a mild traumatic brain injury, concussion can have numerous long-term implications, ranging from increased risk of mild cognitive impairment to more severe neurodegenerative disease.[4]

Importantly, concussion can cause neuromotor deficits that might impact future injury risk. These include reduced cognitive function, impairments in balance, and changes in proprioceptive processing and neuromotor responses during jumping and landing.[5] Typical concussion management protocols in team sports involve the assessment of symptoms, neurocognition, and static balance to assess an athlete's preparedness to return to sport.[6] However, given the breadth of impact associated with concussion, many athletes may return to competition with deficits that impact future risk of injury.[7] This is particularly important in elite junior AF, where medical teams are small, and staff employed on a part-time basis. This could conceivably impact the thoroughness of concussion assessments and associated return to play practices.

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A recent evaluation of National Football Association injury reports indicated that players returning from a concussion do not experience higher injury rates compared to non-concussed players (OR = 0.9, 95 % CI 0.7 to 1.2).[8] However, these findings are notably different to prospective cohort studies. In elite adult rugby players, subsequent injury risk in those returning to play following concussion appears to be significantly greater than those who have not suffered a concussion (IRR = 1.6, 95 % CI 1.4 to 1.8),[9] with similar results observed in multi-sport collegiate athletes (odds ratio [OR] = 3.4, 95 % CI 1.9 to 6.1).[10] Findings are less certain in elite senior AF where the incidence of subsequent injury following a concussion is elevated compared to non-injured control, but associated with wide confidence intervals and a lack of statistical significance (incidence rate ratio [IRR] = 2.2, 95 % CI 0.9 to 5.0).[11] It is also important to note that the research conducted in AF was published in 2009. Since this time rule changes have led to increases in match intensity[12] and the introduction of more stringent diagnostic concussion protocols, which has coincided with increases in reported concussion.[2]

Previous studies in football codes often compare the effect of concussion on subsequent injury using non-injured athletes as the control group.[8,9,11] Given that any index injury (i.e., first recorded injury in a surveillance period) can impact future injury risk,[13] it may be more insightful to explore the risk of subsequent injury after a concussion using non-concussion index injuries as the comparator. Similarly, identifying how the location, mechanism, and severity of subsequent injuries differ after a concussion or non-concussion index injury may better inform injury prevention and rehabilitation strategies (i.e., increase the specificity of rehabilitation strategies following concussion). To date this has only been partially explored in two cohorts. In elite soccer athletes, the risk of subsequent injury after concussion was larger than that experienced after non-concussion index injuries (hazard ratio [HR] = 1.5, 95 % CI 1.1 to 2.1).[14] The associated severity and location of subsequent injuries were not reported. Similarly, in college Football athletes, the odds of incurring a lower limb injury were higher after a concussion compared to an upper limb injury (OR = 1.6, 95 % CI 1.1 to 2.3), although the odds for time loss injury were lower (OR = 0.7, 95 % CI 0.5 to 1.0).[15] Therefore, the impact of concussion on future injury risk, location, mechanism, and severity is largely unexplored across sports, and remains unknown in elite junior AF athletes. Given the common incidence of concussion in AF, and the long-term implications that concussion may have on health and longevity, there is a need for this to be explored.

The primary aim of this study is to compare the risk of subsequent injury after concussion against non-concussion index injury in elite junior AF athletes. The secondary aim is to identify whether subsequent injuries differ in location, mechanism, and severity after concussion and non-concussion index injuries. With previous reports indicating risk of subsequent injury after concussion higher than non-concussion injuries in other football codes,[14,15] the authors hypothesised that injury risk would also be greater after a concussion index injury compared to a non-concussion injury in junior AF.

2. Methods

1455 individual male AF athletes (age: 17.2 ± 0.7 years; height: 181.5 ± 7.4 cm; body mass: 74.8 ± 8.7 kg) from eight elite junior (under-18 years) clubs competing in a state-based competition during seven playing seasons from 2015 to 2022 were recruited (data not collected during 2020 due to covid-19 interruptions). Some players were observed for two seasons, resulting in a total of 1820 player-seasons observed in the study. Of these, 632 unique players sustained an index injury during one or more playing seasons and were included in the subsequent injury analysis (age: 17.1 ± 0.7 years; height: 181.7 ± 7.4 cm; body mass: 74.8 ± 8.6 kg). The inclusion of players with index injuries in multiple seasons resulted in a total of 689 player-seasons being observed for subsequent injury outcomes. This study was approved by an Institutional Review Board ethics committee (protocol number 33950) and consent was obtained from all included participants, with parental/guardian consent obtained for those under 18 years. Athletes were excluded if they failed to play a single game during the season despite being listed in the registered squad or had an index injury that they did not return from (i.e., a season ending injury). It was established that 66 incidents (injuries) per group (concussion vs. non-concussion) were required to provide 80 % power to detect a moderate effect size (HR) of 2.0 at a two-sided 0.05 significance level (Stata Statistical Software, release 17, College Station, TX). Seven seasons were considered appropriate to achieve this based on expected injury rates of at least 10 concussions and non-concussion injuries per season.

2.1. Procedures

The status of each player was tracked weekly during the competitive season using a Player Movement Record (PMR) to identify the number of matches played, the type of injury that occurred, and how many matches were missed due to injury and non-injury reasons. The competition schedule consists of one match per week during the regular season except for 0–2 occasions where a league-wide bye round is scheduled (i.e., all clubs had a week without a match, resulting in 2 weeks between matches). For all injuries identified with the PMR, club physiotherapists or head trainers provided weekly reports on athletes who missed a game due to injury, being defined as "a trauma which caused a player to miss at least one regular-season game", aligning with current industry practice in the competition.[1,2] Importantly, this injury definition was deemed suitable for this population to minimise burden on part-time medical staff, and due to its high accuracy and reliability.[16] As elite junior AF athletes play one game per approximately seven days, this aligns with the inclusion of injuries that are classified of at least moderate severity (8–28 days) in accordance with the consensus statement on injury surveillance in soccer (football).[17] Injuries that did not cause a player to miss a regular season game were not reported, and thus not included in the analysis. Injuries were categorised into seven body locations according to established methodology (head/neck, shoulder/arm/elbow, forearm/wrist/hand, trunk/back, hip/groin/thigh, knee, and shin/ankle/foot), with mechanism being considered contact or non-contact in nature.[1] Injuries were considered as either concussion or non-concussion injury, with non-concussion injuries being further categorised as upper limb or lower limb injuries for primary analysis. The number of matches missed due to injury was captured as a measure of injury severity. The first injury sustained in a single playing season was considered an initial index injury, with any injury occurring after that injury within the same season considered a subsequent injury.

Descriptive statistics (mean ± standard deviation [SD]) were calculated for demographic information. Athletes (n = 632) who sustained an index injury (concussion, upper limb, and lower limb) during each season, and returned to play after that injury, were included in the follow-up analysis to determine the effect of concussion on subsequent injury risk.

Multi-level survival analyses were used to investigate the relationship between the dependent variable (number of games until subsequent injury during the season) and initial index injury group (concussion, upper limb, lower limb) in athletes who got injured and returned to play within the same season. This relationship was also explored for subsequent upper and lower limb injuries. Difference in injury location (head, upper limb, torso, lower limb) and mechanism (contact, non-contact) was compared using a mixed-effects logistic regression. A mixed effects Poisson regression was used to compare the severity of subsequent injuries following an index concussion, lower limb, or upper limb injury, whereby the number of missed matches was used to quantify severity. For all analysis, athlete ID was considered a random effect to account for those athletes who experienced index injuries across multiple seasons. Additionally, exploratory analysis was conducted to determine whether differences in club rehabilitation protocols impacted survival-analysis outcomes by including club as a random effect, and whether changes in concussion management protocols impacted outcomes by including season as a random effect. Effect sizes and 95 % confidence intervals for primary and secondary outcomes are presented where appropriate. Effect sizes were quantified using hazard ratios (HRs), ORs, and IRRs, and considered trivial (0.77–1.00 or 1.00–1.29), small (0.51–0.78 or 1.30–1.99), moderate (0.25–0.50 or 2.00–3.99), and large (≤0.24 or ≥4.00).[18] Athletes that were reported as injured without a location of injury were still included in the analysis for the time period before the unknown injury, with their season ending at the onset of the event without being classified as having a concussion, or an upper or lower limb injury. The level of significance for analysis was set at $P < 0.05$. Analysis was performed using Stata Statistical Software, release 17 (College Station, TX).

3. Results

Of 1455 unique athletes tracked during the 7-year prospective injury surveillance period, 632 sustained an index injury during one or more playing seasons, for a total of 689 index injuries (i.e., some players sustained an index injury in multiple years). All athletes who sustained index injuries were included in the subsequent injury analysis (age: 17.1 ± 0.7 years; height: 181.7 ± 7.4 cm; body mass: 74.8 ± 8.6 kg). Index injury location is presented in Table 1. Index injury severity (missed matches) was 1.4 ± 0.8 for concussion, 3.3 ± 2.4 for upper limb injury, and 3.0 ± 2.8 for lower limb injury.

Of the 689 index injuries, 217 were followed by subsequent injury in the same playing season (head/neck n = 23; shoulder/arm/elbow n = 22; forearm/wrist/hand n = 9; trunk/back n = 16; hip/groin/thigh n = 42; knee n = 27; shin/ankle/foot n = 56; no specific diagnosis available n = 22), of which 70.5 % had a clear verified mechanism (contact n = 84; non-contact n = 69). There was no significant difference between subsequent injury incidence after a concussion and index injuries of the upper (HR = 1.0, 0.6 to 1.9, P = 0.892; *trivial effect*) and lower (HR = 1.1, 0.6 to 1.9, P = 0.810; *trivial effect*) limbs, nor was there any difference in subsequent injury location. There were no significant differences between subsequent lower limb injury incidence after a concussion and upper (HR = 0.8, 0.3 to 1.9, P = 0.560; *trivial effect*) and lower (HR = 1.5, 0.7 to 3.2, P = 0.269; *small effect*) limb index injuries. Similarly, there were no significant differences between subsequent upper limb injury incidence after a concussion index injury and index injuries of the upper (HR = 2.9, 0.8 to 11.0, P = 0.114; *moderate effect*) and lower (HR = 0.5, 0.1 to 1.7, P = 0.256; *moderate effect*) limbs (Fig. 1). Including club or season as a random effect in the survival analysis produced near identical results with no change in statistical significance or direction of the effect size, suggesting potential differences in club rehabilitation and concussion protocols did not influence outcomes. Subsequent injuries were more likely to be contact based after a non-concussion injury compared to a concussion (OR = 4.6, 1.3 to 16.0; P = 0.017; *large effect*) (Table 2).

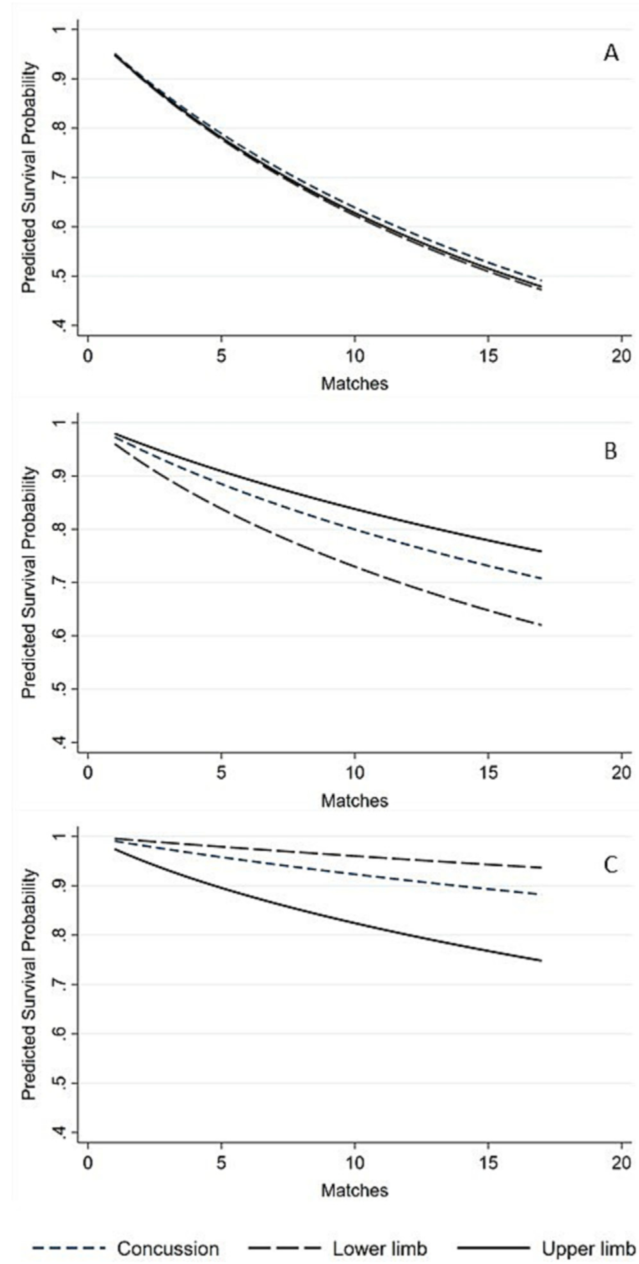

Fig. 1. Predicted mean survival curves for subsequent (A) any injury, (B) lower limb injury, and (C) upper limb injury, after a concussion, upper limb, and lower limb index injury.

Table 1
Index injury location and severity.

Injury location	n (% total)
Head	
Head and neck	15 (2.2 %)
Concussion	69 (10.0 %)
Upper limb	
Shoulder/arm/elbow	61 (8.9 %)
Forearm/wrist/hand	41 (6.0 %)
Torso	
Trunk/back	62 (9.0 %)
Lower limb	
Hip/groin/thigh	141 (20.4 %)
Knee	65 (9.4 %)
Shin/ankle/foot	179 (26.0 %)
Not reported	
Not reported	56 (8.1 %)
Total index injuries	689

n = number of index injuries.

Table 2
Mixed effects logistic regression of subsequent injury location and mechanism after concussion or non-concussion index injury (please note for all analysis, the concussion group is the reference group).

	Concussion (n = 22)	Non-concussion (n = 195)	OR (95 % CI)	P=	ES
Injury region					
Head/neck	2	21	1.2 (0.3 to 5.5)	0.809	Trivial
Upper limb	4	27	0.5 (0.0 to 5.8)	0.580	Moderate
Lower limb	11	114	2.0 (0.3 to 12.8)	0.478	Moderate
Torso[a]	1	15			
Injury mechanism					
Contact	3	82	4.6 (1.3 to 16.0)	0.017*	Large
Non-contact	10	61	0.6 (0.2 to 1.2)	0.152	Small

n = number of athletes who obtained a subsequent injury after an initial index injury in a single season (per group), OR = odds ratio, CI = confidence interval, ES = effect size descriptor.
* Achieved statistical significance (P ≤ 0.05).
[a] Insufficient data available for analysis.

Subsequent injury severity was 3.4 ± 3.0 missed matches after a lower limb index injury, 3.4 ± 3.1 matches after an upper limb index injury, and 2.4 ± 2.0 matches after a concussion index injury. There was no significant difference in the rate of missed matches due to subsequent injury after lower limb (IRR = 1.4, 0.9 to 2.1; P = 0.117; *small effect*) and upper limb index injuries (IRR = 1.4, 0.9 to 2.2; P = 0.189; *small effect*) compared to concussion index injury.

4. Discussion

This is the first study reporting the effect of concussion on risk of subsequent injury in elite junior AF athletes, and whether subsequent injury location, mechanism, and severity differ after a concussion compared to non-concussion index injuries in any sport. Contrary to the hypothesis, risk of subsequent injury was not different after a concussion compared to upper and lower limb injuries, nor was there any significant difference in subsequent injury location or severity. This opposes previous research in soccer[14] and college football athletes,[15] suggesting that different football codes may have different post-concussion injury risk profiles. Additionally, subsequent injuries after a concussion index injury were less likely to be caused by a contact mechanism compared to non-concussion index injuries (both upper and lower limbs).

Junior AF athletes with previous injuries are typically at a greater risk of subsequent injury, and the injury risk appears to be the same when returning from a concussion or non-concussion injury. In elite junior AF, athletes with a previous history of hip and groin injuries have a greater risk of a future hip and groin injury compared to those without such history (IRR = 6.2),[19] with similar results observed in elite senior AF regarding hamstring (OR = 4.3),[20] calf (RR = 4.3) and quadricep (RR = 3.7) strains,[21] and knee injuries (RR = 4.4).[22] Suggestions for the observed increase in injury include a loss of muscle tissue integrity, loss of muscle strength and function, and altered movement in response to pain and immobilisation. Although these explanations are plausible regarding recurrent musculoskeletal injuries, they do not explain the greater risk of injury observed after concussion. Concussions are a unique injury that occur without muscle tissue damage, instead impacting aspects of motor control.[7] As a result, it is highly likely they require different rehabilitation considerations than non-concussion injuries, which are well understood in team-sport contexts. For example, post-concussion gait alterations have been linked to subsequent injury risk[23,24] and comprehensive post-concussion neuromuscular rehabilitation can reduce subsequent injury incidence compared to standard care.[25] Future research should explore the effectiveness of similar post-concussion neuromuscular rehabilitation programmes on subsequent musculoskeletal injury risk in football athletes.

To date, only two prior studies have explored the risk of injury after a concussion using athletes with a non-concussion injury as a control group in football codes. In elite soccer athletes, the risk of any subsequent injury after concussion was slightly larger than that experienced after non-concussion injuries (HR = 1.5),[14] whilst in college football athletes, the risk of a lower limb injury was slightly higher after a concussion compared to a non-concussion upper limb index injury (OR = 1.6), despite the odds for incurring a time loss injury being lower (OR = 0.7).[15] Whilst the reason for these differences is unclear, it could partially be explained by differences in injury definition. The "missed-match" injury definition used in the current study does bias towards more severe (>7 days) injuries. It could be that post-concussion impairments that may increase injury risk are more likely to result in less severe injuries that do not result in a player missing a game (such as minor strains or contusions). This may explain why the aforementioned research in college football athletes found an increased risk of non-time loss injury post-concussion, but not for time loss injury.[15] This suggestion may be further supported when considering prior research conducted in elite National Football League athletes, where concussion did not appear to increase injury risk.[8] In this analysis data was collected by examining previously published injury reports, which often demonstrate a lack of transparency on reporting, and may have tendency to only report more severe injury types. Additionally, both prior studies outlined above were conducted in adults (aged >18 years).[14,15] It may be that post-concussion injury risk is heightened in adult athletes who are likely to have more robust strength and power characteristics, and therefore more likely to experience greater acceleration and deceleration forces during actions associated with injury, such as jumping, landing, and changing direction.[5] Future research should explore whether athletes with greater strength and power capabilities are more prone to subsequent injuries after concussion.

Interestingly, whilst concussion likely increases subsequent injury risk through different mechanisms than non-concussion injuries, the location of subsequent injuries did not differ between injury categories in this study. These findings align with previous research conducted in elite senior AF, where 67 % of athletes who sustained two injuries in a single season had a subsequent injury unrelated to the first.[13] This suggests that any injury could contribute to a problematic injury burden cycle, potentially impacting player success and career progression.[19] When considering concussion injuries specifically, this may indicate that the time spent in recovery is insufficient to regain all affected capabilities. In junior AF, there are strict return-to-play guidelines following a concussion injury, whereby the earliest an athlete can return to competition is 12 days post-concussion.[26] However, a recent consensus statement on concussion in sport has indicated that children and adolescents may take up to 4 weeks to recover from a sport related concussion.[27] The athletes in this study missed an average of 1.4 games (likely <14 days between concussion and return to competition) after sustaining an initial index concussion injury, suggesting some athletes may have been returning to playing commitments (i.e., training) based upon the 12-day minimum, rather than after achieving full recovery. A recent study reported a mean return to play time of ~20 days in male intercollegiate athletes when adhering to an exhaustive return to play protocol (based on the 2012 Zurich consensus statement on concussion in sport),[28] which supports our interpretation. Similarly, research in a large cohort of American college athletes indicated that 57 % of the athletes in their study cleared return to play protocols after a concussion in 14 days, with that number reaching 77 % three weeks post-concussion.[29] As youth appear to take longer to recover from concussion,[27] this is of particular importance. Given the highly competitive nature of elite sport, there may be a desire to rush an athlete's return to competition to gain a competition advantage.[30] Or, in the case of elite junior sport, there is the potential for athletes to overplay their perceived readiness after injury in response to fear of missing games[31] – particularly as participation directly impacts their likelihood of being drafted to an elite senior level of competition.[32] Given the possible deleterious effects of concussion on youth, this may highlight the need for more careful implementation and monitoring of return-to-play guidelines in junior AF.

Whilst location did not differ, there was a difference in injury mechanism, where subsequent injuries occurring after a concussion were less likely to be contact in nature. The reason for this finding is not clear, although there is evidence of youth athletes demonstrating notable fear of reinjury after concussion, even after being cleared to participate.[33] It is possible that players may be less likely to engage in contact situations after a concussion due to fear of reinjury. Similarly, whilst not significant, there was a small effect for subsequent injuries after a concussion being more likely to have a non-contact mechanism. Prior research on concussed athletes have shown reductions in maximal voluntary muscle activation, loss of balance, and impaired neuromuscular performance during gait, which is further exacerbated with increases in cognitive demand.[5] It is possible that these deficits could result in a heightened risk of injury during high velocity actions, such as sprinting, jumping, and changing direction, particularly if they occur during match-play scenarios that involve opposition players. This provides an example of how different subsequent injury risk mechanisms may inform different rehabilitation considerations for athletes returning from concussion. Future research should explore optimal rehabilitation and injury prevention strategies following a concussion in team sport athletes.

There are some limitations that should be considered when interpreting these findings. Only including injuries that are deemed at least 'moderate' severity biases towards more serious injuries.[17] As such, if any athletes suffered an injury that did not require missing a match (<7 days), they were not reported as injured. There is some evidence to suggest that concussion increases risk of subsequent injuries that are minor in nature (<7 days),[15] which would not have been identified in the current study. Additionally, considering that there can be up to two league wide bye rounds per season, using this definition means that an athlete injured prior to a bye round may have been recorded as having a lower injury severity than their "true" injury severity (e.g., they had an injury that took two weeks to recover from but was only recorded as one-week severity). It is also important to note that this study only included index and subsequent injuries that occurred in the same season. There is some evidence indicating that risk of subsequent injury post-concussion may increase over time,[34,35] which was not assessed in this cohort. Finally, a clear mechanism was only provided for approximately 70 % of the subsequent injuries in this study, which may reduce confidence in some of these mechanism related findings.

5. Conclusion

In conclusion, the risk, anatomical location, and severity of subsequent injury in junior AF are similar following concussion compared to non-concussion index injuries. However, contact injuries are less likely after a concussion index injury. Due to the unique nature of concussion injuries, they likely require different rehabilitation considerations than other musculoskeletal injuries. Future research should aim to identify optimal rehabilitation and injury prevention strategies following a concussion.

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Confirmation of ethical compliance

This study was approved by an institutional Review Board (protocol number 33950), and participants provided written informed consent to participate in the study. Parental or guardian consent was obtained for athletes under 18 years.

CRediT authorship contribution statement

Hunter Bennett: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Samuel Chalmers:** Methodology, Investigation, Resources, Data curation, Writing – review & editing, Visualization, Project administration. **Joel Fuller:** Methodology, Formal analysis, Investigation, Resources, Writing – review & editing, Visualization, Project administration.

Declaration of interest statement

The authors declare no conflicts of interest.

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