Australian Football League Injury Characteristics Differ Between Matches and Training

A Longitudinal Analysis of Changes in the Setting, Site, and Time Span From 1997 to 2016

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Background: Injury surveillance has been used to quantify the scope of the injury burden in Australian football. However, deeper statistical analyses are required to identify major factors that contribute to the injury risk and to understand how these injury patterns change over time.

Purpose: To compare Australian Football League (AFL) injury incidence, severity, prevalence, and recurrence by setting, site, and time span from 1997 to 2016.

Study Design: Descriptive epidemiology study.

Methods: A total of 15,911 injuries and medical illnesses recorded by team medical staff at each club were obtained from the AFL's injury surveillance system and analyzed using linear mixed models with 3 fixed effects (setting, time span, site) and 1 random effect (club). All types of injuries and medical illnesses were included for analysis, provided that they caused the player to miss at least 1 match during the regular season or finals. Five-season time spans (1997-2001, 2002-2006, 2007-2011, and 2012-2016) were used for comparisons. Incidence rates were expressed at the player level. Recurrences were recoded to quantify recurrent injuries across multiple seasons.

Results: Compared with training injuries, match injuries had a 2.8 times higher incidence per season per club per player (matches: 0.070 ± 0.093; training: 0.025 ± 0.043; $P < .001$). Match injuries resulted in 1.9 times more missed matches per club per season (matches: 17.2 ± 17.0; training: 9.1 ± 10.5; $P < .001$). and were more likely to be recurrences (matches: 11.6% ± 20.0%; training: 8.6% ± 21.8%; $P < .001$). From the 1997-2001 to 2007-2011 time spans, overall injury severity increased from a mean of 3.2 to 3.7 missed matches ($P \leq .01$). For the most recent 2012-2016 time span, injuries resulted in 3.6 missed matches, on average. Hip/groin/thigh injuries had the highest incidence (0.125 ± 0.120) and prevalence (19.2 ± 16.4) rates, and recurrences (29.3% ± 27.9%) were 15% more likely at this site than any other injury site.

Conclusion: The risks of match injuries are significantly higher than those of training injuries in the AFL. Compared with the 1997-2001 time span, injuries became more severe during the 2007-2011 time span.

Keywords: Australian football; epidemiology; medical aspects of sports

From a medical perspective, an injury is defined as any physical complaint that is caused by the inability of the body's tissues to maintain their structural and/or functional integrity.[14] Comprehensive surveillance of injuries and their characteristics (eg, incidence, severity, prevalence, recurrence) is important to record so that thorough investigations of such data can uncover meaningful patterns to inform injury prevention priorities and strategies. Through injury prevention, short- and long-term consequences associated with an injury can be diminished by lowering treatment costs, decreasing the risks of chronic musculoskeletal conditions, and minimizing time lost from further participation.[10,20,38] At the elite level,[20] contact team ball sports, such as Australian football, generally incur a higher risk of injuries than other sports.[10]

Australian football is characterized by intermittent and high-intensity running, ball disposal skills executed by hand and foot, abrupt changes of direction, tackling, and

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regular jumping/landing over continuous quarters of play that last approximately 30 minutes.[16] The numerous ways of being exposed to unbraced contact, combined with the range of dynamic skills and movements performed, expose Australian football players to a high injury risk.[7,13] The Australian Football League (AFL), the pre-eminent professional league for Australian football, has established the longest-running injury surveillance system in Australia and has achieved complete compliance in recording all injuries that have resulted in missed AFL matches since 1997.[26,28] This comprehensive injury database has demonstrated value as an informative identification tool for injury research in Australian football.[31] However, it is worth noting that 60 rule changes have occurred in the past 20 years,[3] and the professionalization of the sport continues to grow (as shown by increased investment in medical and performance staff). Thus, further injury research is warranted for monitoring trends and detecting emerging injury patterns in an ever-evolving sport.

Summary statistics drawn from longitudinal injury data can help to quantify the scope of the injury burden in Australian football. Over a 21-year period from 1992 to 2012, each club, which has an average list size of 44 players, experienced approximately 37 new injuries and 5 recurrent injuries, which resulted in 42 total injuries and 139 missed matches per season.[32] The average injury severity was 4 missed matches, and 14.5% of injuries sustained throughout the entire 21-year period were recurrent injuries.[32] Building on this work requires the application of deeper statistical analyses to identify major factors that contribute to the injury risk and to understand how these injury patterns change over time. For instance, the characteristics of AFL injuries may differ depending on the setting in which an injury occurs (eg, matches vs training).[12,24,36] Research in elite soccer has shown that the injury incidence is 6.7 times higher during matches compared with training.[12] Similarly, 147 match injuries compared with 7 training injuries per 1000 hours of exposure have been reported in junior Australian football players[24]; however, this has not been investigated at the elite level. Injury sites that have been categorized into general body regions are commonly reported in the literature on elite Australian football.[2,32] However, differences in injury characteristics between these sites have never been established.

The purpose of this research was to investigate longitudinal injury patterns in the AFL and factors contributing to the injury risk, with a view to informing the development and prioritization of injury prevention strategies. Specifically, the aim of this study was to compare whether AFL injury characteristics (incidence, severity, prevalence, and recurrence) differed by setting, site, and time span from 1997 to 2016.

METHODS

Participants

All injuries and medical illnesses over the 20-season period from 1997 to 2016 were obtained and analyzed from the AFL's injury surveillance system. A total of 2738 of a possible 2996 unique AFL listed players (91%), from 20 clubs that play in 22 regular-season matches per season (and if applicable, a maximum of 4 finals matches per season), contributed to 15,911 injuries or medical illnesses available. The age (mean, 23.8 ± 4.0 years) of the injured or medically ill players ranged from 17.4 to 40.1 years. Players were included in the injury surveillance system if they adhered to the injury definition of sustaining an injury or medical condition that caused them to miss at least 1 match during the regular season or finals.[32] This "time loss" definition is in accordance with consensus statement recommendations to allow complete or near complete compliance for homogenous injury recording of elite athletes.[17,18,30]

Each injury was recorded electronically by team medical staff at each club and then exported to a common database at the end of each season. The injury diagnosis was subsequently coded using the Orchard Sports Injury Classification System[27,33] and was categorized into 10 general body regions (forearm/wrist/hand, general soreness/fatigue, head/neck, hip/groin/thigh, knee, medical illnesses, nonfootball injuries, shin/ankle/foot, shoulder/arm/elbow, trunk/back). These injury site categorizations are consistent with those in previously reported AFL injury surveillance system data.[32] All injuries were recorded as either being sustained during competition (matches), during training, or outside of a football environment (other). Player consent for this procedure lies within standard AFL player contracts. This study was approved by the Deakin University Human Ethics Advisory Group, AFL, AFL Doctors Association, and AFL Players Association.

Injury Characteristics

The injury characteristics examined in this study were incidence, severity, prevalence, and recurrence. Injury incidence refers to the total number of injuries in relation to the amount of exposure. In contrast to previous literature calculating injury incidence rates by standardizing club list sizes to 40 players,[32] this study used the exact number of

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listed players for each club per season. It was decided to establish and report the incidence rate on a player level to avoid underreporting. For example, club A sustaining 45 injuries appears to be less than club B sustaining 53 injuries in a season. However, if club A had 39 players and club B had 46 players on their list, it would equate to the same incidence rate of 1.15 injuries per player per club per season. This new calculation enables seasons to become comparable, as list sizes have ranged from 39 to 55 over the 20 seasons.

Injury severity refers to the number of missed matches for each specific injury, whereas injury prevalence is a product of incidence and severity and refers to how many players in a club are restricted by an injury during a set time period. In this study, injury prevalence is represented by the number of missed matches per club per season. Studies emanating from the AFL's injury surveillance system typically report an injury as a recurrence if it is of the same type, site, and side (if applicable) and causes further missed matches within the same season.[32] A previous injury is the strongest risk factor for future Australian football injuries[19,23,39]; therefore, this study has retrospectively reclassified recurrent injuries based on a player's first index injury appearing in the AFL's injury surveillance system. Treating all seasons together rather than separately adheres to current injury categorization guidelines.[14] To avoid overreporting recurrence rates, the current study divided recurrent injuries by the total number of injuries[15] rather than the number of new injuries.[32] For example, if a club sustained 42 injuries comprising 22 recurrences, the recurrence rate was reported as 52% (22 recurrences/42 total) instead of 110% (22 recurrences/20 new). Medical illnesses were removed from all recurrence analyses, as they were not categorized into a site and side.

Statistical Analysis

R was used for data preparation and visualization.[1,40,41] All analyses were conducted using SPSS (v 24; IBM). Statistical significance was set at $P < .05$. Descriptive statistics are presented as mean ± SD for setting, site, and time span. The final parameter estimates are reported in text as β coefficient ± standard error of the estimate. Exploratory data analysis confirmed that the data structure met parametric assumptions.

Linear mixed models were constructed for each injury outcome variable, comprising 3 fixed effects (setting × time span × site) and 1 random effect (club). Where main effects were statistically significant, interactions were also analyzed. Within each model, injury site (categorized as a general body region) was explored on 10 levels (eg, forearm/wrist/hand), setting was explored on 3 levels (matches, training, and other), and 5-season time spans were explored on 4 levels (1997-2001, 2002-2006, 2007-2011, and 2012-2016). Competitive-season training injuries were more likely to be reported because of the nature of the injury definition. Clubs may influence the outcome variables; however, they could not be controlled. Therefore, clubs were examined as a random effect. As an example of how to interpret the rates provided from the linear mixed-model outputs, consider a club of 44 listed players who sustained an average of 26 hip/groin/thigh injuries that caused 94 missed matches each season during the 1997-2001 time span. The injury incidence rate would equate to 0.59 injuries per player per club per season, and each injury would cause 3.62 missed matches. If 7 of these 26 injuries were recurrences, then the recurrence rate would equate to 27%.

RESULTS

Effects of Setting, Time Span, and Site

In matches, the injury incidence ($\beta = 0.05 \pm 0.00$), prevalence ($\beta = 9.85 \pm 0.40$), and recurrence ($\beta = 3.03 \pm 0.48$) rates were higher than in training ($P < .001$ for all) (Figure 1). The severity of injuries sustained from matches ($\beta = -0.14 \pm 0.10$) was similar to the severity sustained from training. From the 1997-2001 to 2007-2011 time spans, injury severity and prevalence increased ($P \leq .01$ for both), however injury incidence and recurrence rates did not change over the time spans (Figure 2). There were several injury incidence, severity, prevalence, and recurrence differences with respect to the injury site (Figure 3). The most severe injuries in the were in the knee (5.8 missed matches per player per season), shoulder/arm/elbow (4.2 missed matches per player per season), and shin/ankle/foot (3.6 missed matches per player per season). The highest recurrence rates stemmed from hip/groin/thigh (29.3%), shin/ankle/foot (14.0%), and knee injuries (12.3%). The 29.3% recurrence rate for hip/groin/thigh injuries was 15% more likely than any other injury site, and the incidence (0.125 ± 0.120) and prevalence (19.2 ± 16.4) rates for this site were also the highest.

Injury Prevalence Interactions Between Time Span, Site, and Setting

Boxplot descriptive statistics overlaid with individual club data points for each season were used to display the 3-by-3 interaction between time span, site, and setting on injury prevalence (Figure 4). This reiterates the effects of each individual factor and shows how they interact together. Injury prevalence was used to demonstrate differences, as it also reflects the incidence and severity rates. The most notable interaction was the increase of shin/ankle/foot match injuries from the 1997-2001 (22.3 ± 15.5) to 2012-2016 (33.7 ± 18.6) time spans ($P < .001$).

DISCUSSION

The major findings of this study were that match injuries have a higher incidence rate, cause more missed matches per club per season, and are more likely to be recurrent injuries than injuries sustained in training settings. Injuries have also become more severe from the 1997-2001 to 2007-2011 time spans. Australian football is a multifaceted and ever-changing sport, especially considering the numerous game styles, tactics, and rule changes that have occurred over the past 20 seasons. Controlling for all

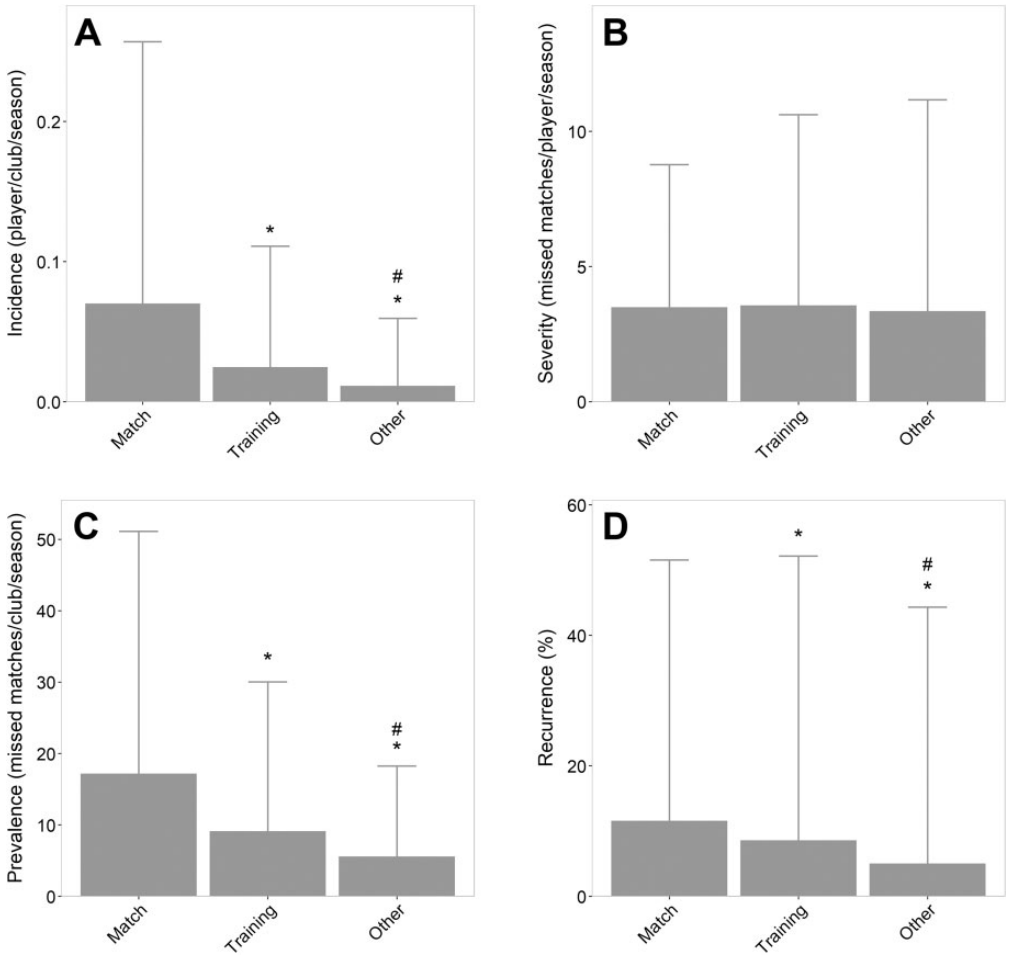

Figure 1. Pairwise comparisons of injury (A) incidence, (B) severity, (C) prevalence, and (D) recurrence between settings. *Significantly different from matches ($P < .001$) and #significantly different from training ($P < .001$).

possible confounders is not feasible, so explanations for these differences have been made by placing this study's findings in the context of the relevant previous literature and supplementary AFL material.

Effect of Setting on Injury Characteristics

The injury incidence was found to be 2.8 times higher during matches compared with training. ($P < .001$). It is important to note that these values were not adjusted for exposure hours in each setting. In a similar study focusing on elite soccer, after adjusting for exposure hours, the injury incidence was 6.7 times higher during matches compared with training.[12] Using the same cohort, match density in a competition setting was found to be associated with increased injury rates.[4] The current study found that match injuries resulted in 1.9 times more missed matches per club per season than training injuries ($P < .001$). This difference was predominantly because of differences in incidence rates between these settings, as there is no practical difference in the severity of injuries sustained in matches versus training (3.5 vs 3.6 missed matches, respectively). Our analyses also revealed that injury recurrences occurred 1.4 times more often in matches compared with training ($P < .001$).

Unplanned movement patterns,[8] match tactics,[29] and receiving contact while fatigued[6] are each associated with an increased injury risk in Australian football. These circumstances can all be avoided during training. Research on American collegiate football has found that match injuries occur 9 times more frequently than injuries during in-season training.[11] The authors of that study speculated that this increase was caused by the increased intensity of matches and subsequent increase in the number and magnitude of collisions. This speculation is supported by more recent research reporting that 72% of all American collegiate football match injuries were caused by direct player contact.[42] Furthermore, research on elite Australian football has found that in-season training generally does not involve physical pressure (eg, contact). As a result, it may not adequately meet the contested possession and physical actions (eg, tackles, spoils) associated with the demands of matches.[9] Research on junior Australian football players has found that match injuries are more likely to occur than training injuries, with incidence rate differences of 140 injuries per 1000 exposure hours reported.[24,36] It is

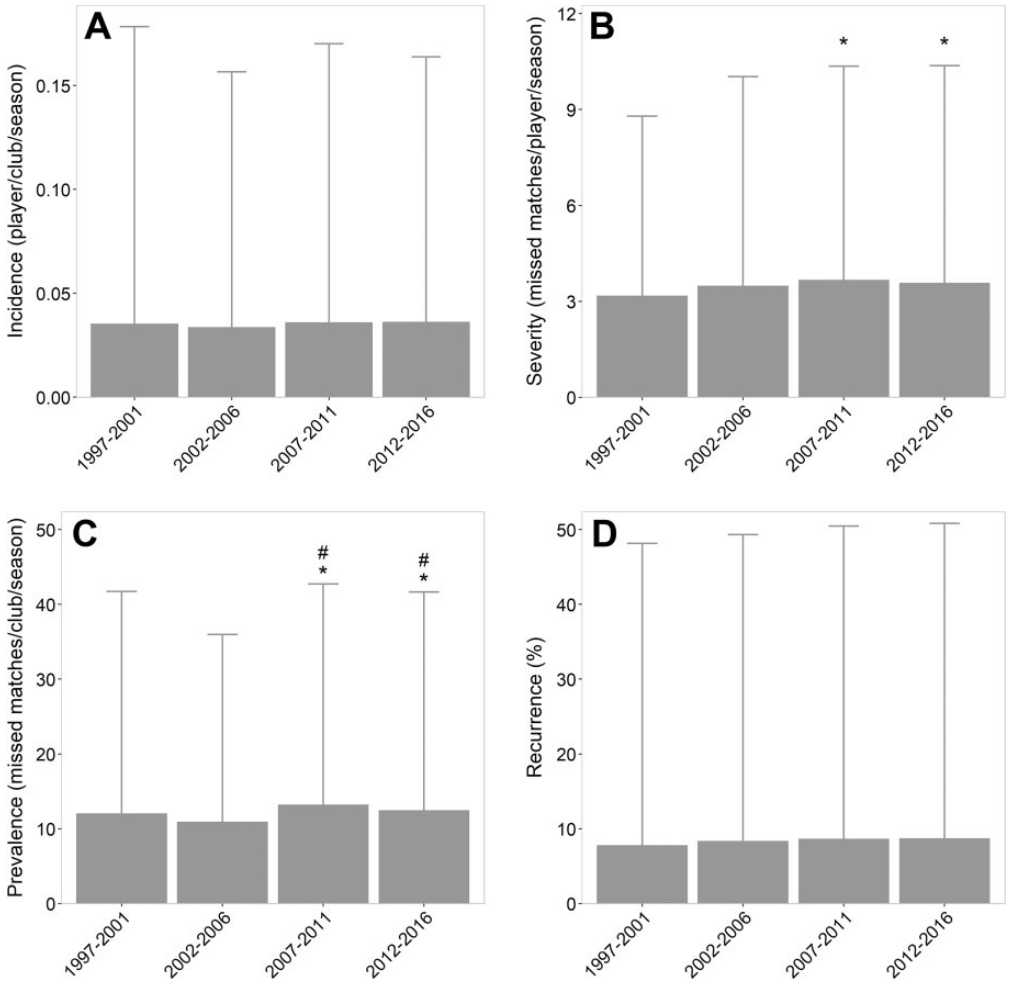

Figure 2. Pairwise comparisons of injury (A) incidence, (B) severity, (C) prevalence, and (D) recurrence between time spans. *Significantly different from 1997-2001 ($P \leq .01$) and #significantly different from 2002-2006 ($P \leq .01$).

plausible to suggest that physical pressure that is driven by player density in a given area, intensity, magnitude and frequency of contact, and loads are typically increased during matches compared with training, especially with the added incentive of winning, and may subsequently cause higher injury incidence and recurrence rates.

Effect of Time Span on Injury Characteristics

The severity of each injury gradually increased by half a missed match from the 1997-2001 to 2007-2011 time spans; this difference between the time spans was statistically significant ($P \leq .01$). The difference may be explained by the increased intensity and rates of contact in Australian football during this period. Although interchange rotations were only recorded from 2003 onward, they increased from an average of 35 to 93 rotations from 2003-2006 to 2007-2011 (Champion Data, unpublished data, April 2018). Previous research has demonstrated that players produce higher mean speeds in the first few minutes of each quarter and that players who are rotated on and off the bench more frequently perform an increased number of high-intensity efforts.[25] Furthermore, changes in match features such as the percentage of time that the ball is in play and ball speed (m/s) indicate that an increase in match flow and speed occurred from 2001 to 2007.[22] It is reasonable to suggest that increases in overall speed may increase collision force and/or contribute to higher volumes of high-speed running,[43] which may have caused the increase in overall injury severity.

Impact of Rule Changes on Injury Severity

Strategies to reduce match density during the 2012-2016 time span (listed in Appendix Table A1) may have offset the increased injury severity rates.[3,34,37] Coupled with recent rules to control interchange rotations,[5,35] they are plausible to reduce players' on-field recovery and their subsequent ability to maintain high match speeds.[22] These measures may increase both transient and cumulative fatigue,[6,29] which are known to increase the injury risk. However, injury incidence did not increase during the 2012-2016 time span. As injury severity did not differ between the 2007-2011 and 2012-2016 time spans, this may suggest that the rule

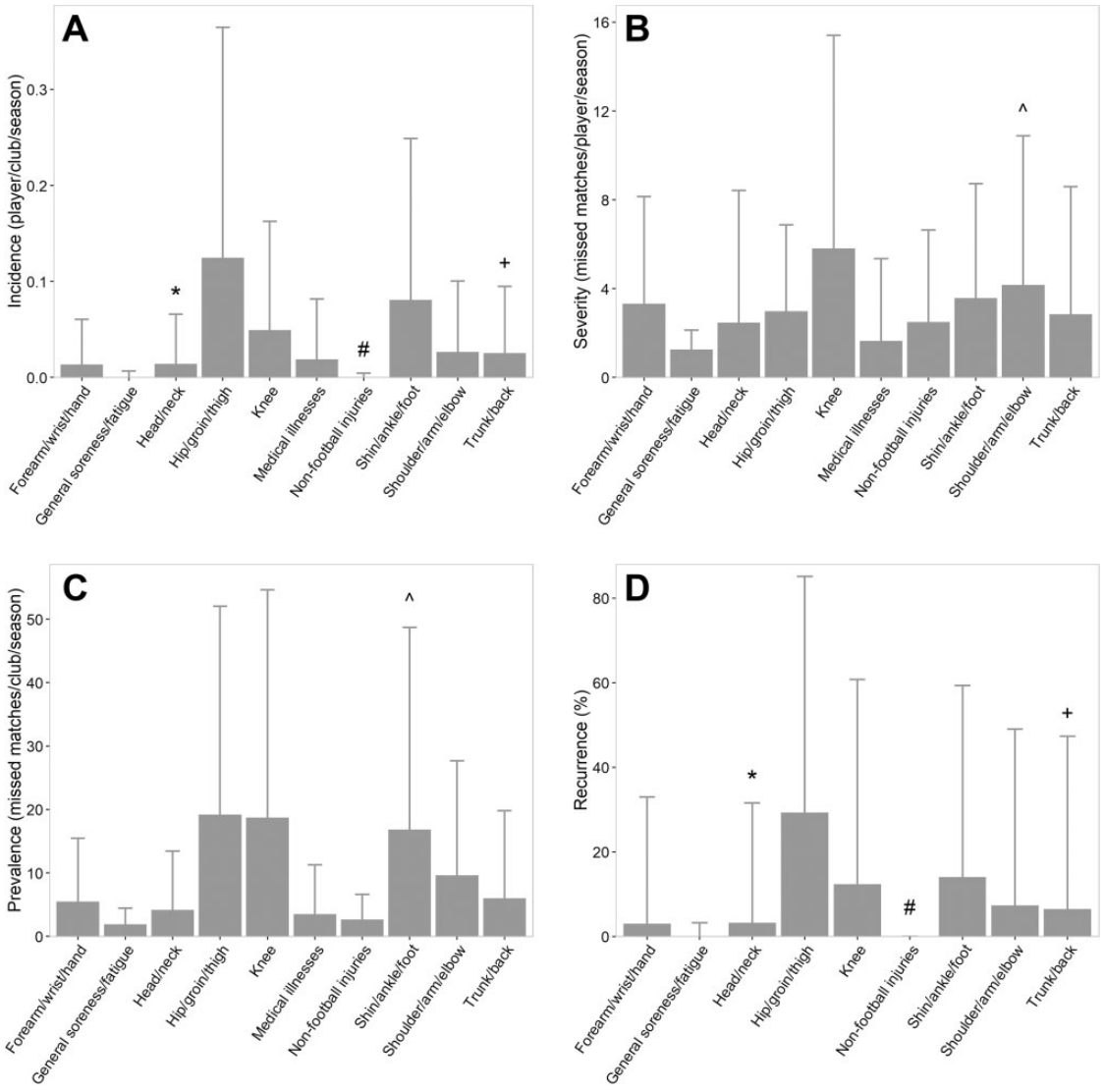

Figure 3. Pairwise comparisons of injury (A) incidence, (B) severity, (C) prevalence, and (D) recurrence between sites. There were significant differences ($P < .05$) between all sites for all 4 injury characteristics. However, the exceptions to this were the following: *not significantly different from forearm/wrist/hand, #not significantly different from general soreness/fatigue, ^not significantly different from nonfootball injuries, and +not significantly different from shoulder/arm/elbow.

changes imposed had no effect on injuries, including those specifically aiming to reduce the risk of serious injuries and increase player safety (listed in Appendix Table A2).[3]

It is worth noting that the rule changes may have had an effect that was masked by a change toward more conservative injury management strategies to reduce the risk of recurrent injuries.[21] Yet, this is not reflective of the 2012-2016 recurrence rate in the current findings. If injuries have been managed more conservatively and recurrences have not differed, it is reasonable to suggest that some injured players can return to competition earlier without an increased risk of sustaining a recurrence. Further research differentiating the effect of missed matches for each injury site on the recurrence risk is recommended. Research investigating the relationship between rule changes and injury rates that account for specific sites and their mechanisms is also warranted.

Effect of Site on Injury Characteristics

The findings of the most common injury sites of hip/groin/thigh, shin/ankle/foot, and knee are in agreement with a previous study reporting the 2003-2012 incidence rates from elite Australian football.[32] However, the order of the most prevalent sites differs from the previous study, as after hip/groin/thigh injuries, the current study found knee injuries, followed by shin/ankle/foot injuries, to be the most prevalent. Furthermore, the findings in the current study revealed that shin/ankle/foot injuries progressed from the third to the first most prevalent match injury site over the past 20 seasons,

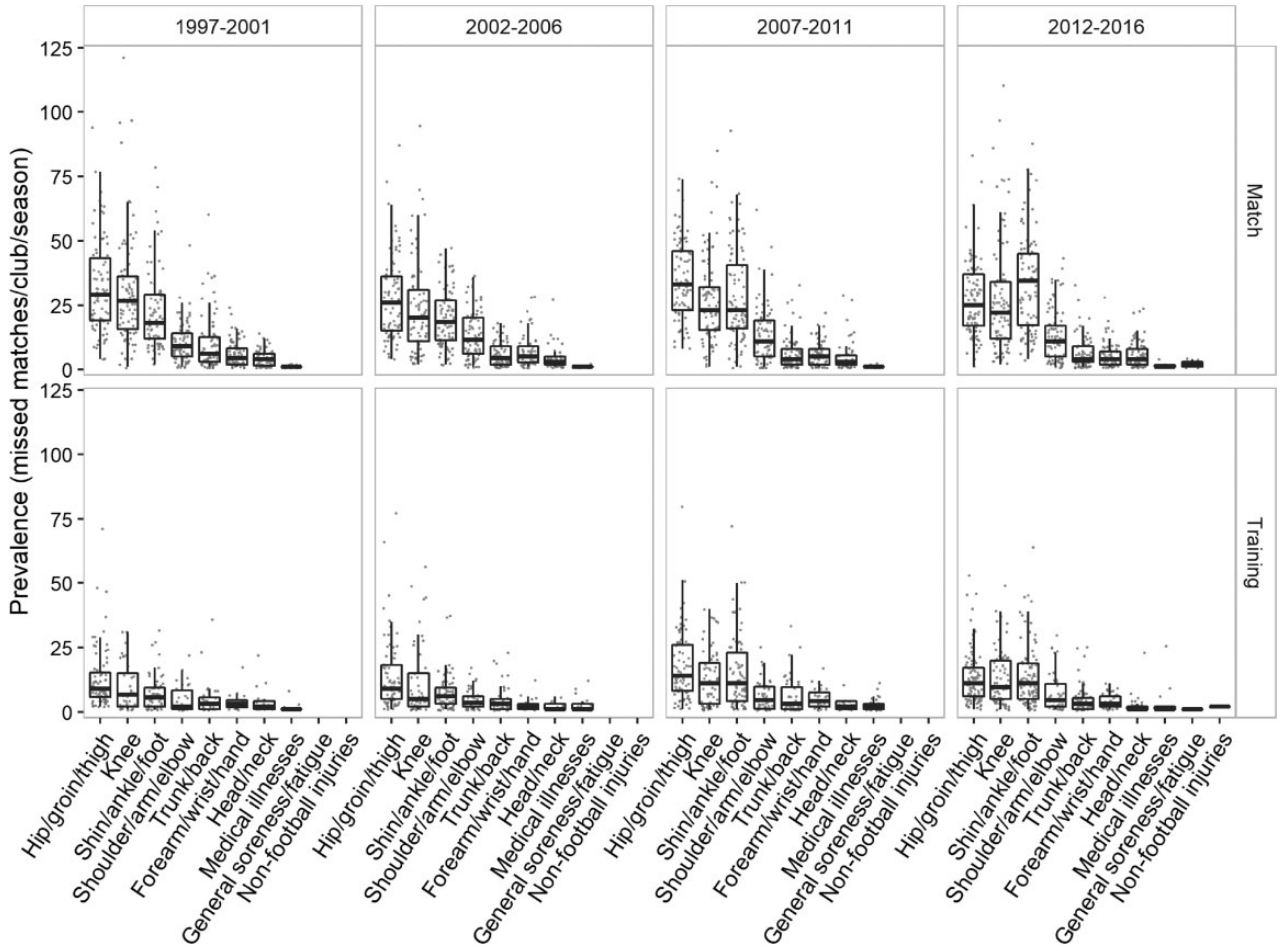

Figure 4. Injury prevalence interaction between time spans, sites, and settings.

increasing by 11.4 missed matches per club per season (51%). Considering that we do not know whether these are acute or overuse injuries, we cautiously speculate that this increase could be caused by an increase in running speed, player density in a given area, or training loads. Although overall injury severity has increased over the past 2 decades, it may reflect a different injury profile. Rates cannot be directly compared, as different analyses were performed; however, the order of the most prominent rate can when examining the same population. The findings of the current study reinforce those of previous studies that the lower limb is clearly the site of the most injuries.[16,32]

To our knowledge, this is the first study to report severity and recurrence rates for sites that have been categorized into general body regions in elite Australian football. The results suggest that increased resources and/or a more conservative approach toward injury prevention management are advised for players who have sustained at least 1 previous hip/groin/thigh injury. Furthermore, these findings add to the current literature that previous injuries are the strongest risk factor for future injuries.[23] It is recommended that future research aim to explore the relationships of subsequent injuries other than recurrences.

Limitations

It is important to acknowledge the limitations associated with the injury definition. Some injuries appear less severe, as injuries sustained during the offseason, preseason, or leading into a bye round are when matches are not played. Therefore, time missed in weeks does not always equate exactly to the number of missed matches, such that injury severity may be slightly underestimated. Furthermore, there is a possibility that some injuries may have never been entered into the database. Although the flaws are important to consider, this injury definition has enabled complete compliance and consistency from all 18 AFL clubs across 20 seasons.[17,18,30] Reporting specific injury diagnoses would be more meaningful to practitioners than the broad categorizations of general body regions. However, the injury surveillance database consisted of 36 specific injury types, which are too many levels to run a linear mixed model. Performance data after players return from injuries would also provide further insight on the effectiveness of injury rehabilitation programs and/or time-to-return decisions (eg, whether conservative management should be considered, affecting the number of missed matches).

CONCLUSION

The risks of match injuries are significantly higher than those of training injuries in the AFL. Time loss from injuries has increased from the 1997-2001 to 2007-2011 time spans and has remained similar during the 2012-2016 time span. The current findings further support results that injury incidence, severity, prevalence, and recurrence of the lower limb are considerably greater than those of the upper limb. Hip/groin/thigh recurrences were more than 2 times likely to occur than any other general body region, and shin/ankle/foot match injuries increased by 11.4 missed matches per club per season (51%) over the past 20 seasons to become the most prevalent general body region in matches.

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APPENDIX

TABLE A1
Rule Changes to Reduce Match Density in the Australian Football League[3,35,38]

Year	Rule Revision
2011	Stricter interpretation placed on deliberate out-of-bounds rule
2013	A throw-up of the ball by field umpires to replace all field bounces; center bounces at the beginning of the quarter and after goals continue as previously
2013	Compulsory noncontact by opposing ruckmen before the ball leaving an umpire's hand at all stoppages
2015	Stricter interpretation of prior opportunity in which a player has not elected to take a previous chance to dispose of the ball (choosing to evade, feign, etc)
2016	A stricter interpretation of deliberate out of bounds applied based on a player's not showing enough intent to keep the ball in play

TABLE A2
Rule Changes to Reduce the Risk of Serious Injuries and Increase Player Safety in the Australian Football League[3]

Year	Rule Revision
2012	Sliding knees or feet first into an opposing player prohibited
2013	Forceful contact below the knees of an opponent prohibited