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Original Research

Training and game loads and injury risk in elite Australian footballers

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ABSTRACT

Objectives: To examine the relationship between combined training and game loads and injury risk in elite Australian footballers.
Design: Prospective cohort study.
Methods: Forty-six elite Australian footballers (mean ± SD age of 22.2 ± 2.9 y) from one club were involved in a one-season study. Training and game loads (session-RPE multiplied by duration in min) and injuries were recorded each time an athlete exerted an exercise load. Rolling weekly sums and week-to-week changes in load were then modelled against injury data using a logistic regression model. Odds ratios (OR) were reported against a reference group of the lowest training load range.
Results: Larger 1 weekly (>1750 AU, OR = 2.44–3.38), 2 weekly (>4000 AU, OR = 4.74) and previous to current week changes in load (>1250 AU, OR = 2.58) significantly related ($p < 0.05$) to a larger injury risk throughout the in-season phase. Players with 2–3 and 4–6 years of experience had a significantly lower injury risk compared to 7+ years players (OR = 0.22, OR = 0.28) when the previous to current week change in load was more than 1000 AU. No significant relationships were found between all derived load values and injury risk during the pre-season phase.
Conclusions: In-season, as the amount of 1–2 weekly load or previous to current week increment in load increases, so does the risk of injury in elite Australian footballers. To reduce the risk of injury, derived training and game load values of weekly loads and previous week-to-week load changes should be individually monitored in elite Australian footballers.

1. Introduction

Playing Australian football requires repeated physical contact and movements involving endurance, speed and acceleration[1] over match durations of 100+ min.[2] Recently, Australian Football League (AFL) interchange rates have dramatically increased, allowing players additional breaks throughout games, possibly contributing to higher mean game speeds.[3] With greater player physical demands,[1,4] injury incidence and prevalence rates have also increased.[3] During 2010, each AFL club (on average) experienced 38.6 new injuries, causing a player to miss one or more games. Overall, player injuries resulted in an average of 153.8 missed games per club.[3]

Understanding potential mechanisms of sporting injuries is important to AFL medical and conditioning staff, as they manage their players to be fit for matches. Training and game overload is one possible cause of injury, therefore monitoring these loads in players is important. Measuring training and game loads exerted by athletes can be done by multiplying session rating of perceived exertion[5] (Borg CR10 RPE) and duration (min). Previous studies have analysed the relationship between load exerted and injury risk in team sports including sub-elite[6] and professional rugby league,[7] soccer,[8] basketball[9] and cricket.[10]

Gabbett and Domrow[6] analysed training loads and injuries of 183 sub-elite rugby league players, finding increases in odds of injury in pre-season (OR = 2.12, $p = 0.01$), early competition (OR = 2.85, $p = 0.01$) and late competition (OR = 1.50, $p = 0.04$) phases, for each increase in a log (150 arbitrary units) of training load. Orchard et al.[10] reported cricket bowlers completing more than 50 overs in a match had a significantly increased risk (1.77 times) of injury in the next 14–21 days compared to bowlers completing less than 50 overs. The delayed effect of the load of previous weeks is important to consider when analysing load and injury relationships.

Piggott et al.[11] analysed the relationship of injury and illness with weekly training load in 16 AFL players across a 15-week pre-season training phase. No significant relationships were reported between injuries or illness and training load across this period. However, studies using a larger sample and conducted over a longer

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time period may provide a more comprehensive understanding of the relationship between training load and injury in AFL players.

Each year approximately 4–8 new rookie players are drafted into AFL clubs, coming primarily from junior competitions and State leagues. Senior AFL players have significantly more lean body mass and bone mineral density than State junior players,[12] which is likely a result of physical maturation from previous training and game loads within the elite system. Greater movement demands in the AFL compared to State leagues[13] further highlights the increased physical demands required of junior or sub-elite players in making the transition into the professional AFL game and training environment. Therefore, exploring the training and game load tolerance of players with different years of experience at an elite level is important.

To date, studies of the training load-injury relationship of AFL players are limited, with the only study performed restricted to a small sample of AFL players over a pre-season period.[11] Therefore, the aim of the present study was to examine the relationship between training and game loads and injury risk in AFL players from a full club squad, across an entire season. Identifying a relationship between load and injury may allow club staff to make more objective decisions on when players are at increased risk of injury.

2. Methods

Elite ($n = 46$) Australian footballers were involved in this prospective study. Their mean ± SD age, stature and body mass were 22.2 ± 2.9 years, 187.7 ± 7.5 cm and 85.4 ± 8.9 kg, respectively. All were from one AFL club and competed in matches in the AFL or Western Australian Football League (WAFL) during 2010. The AFL team played 22 competition matches but did not qualify for finals. All players provided informed written consent prior to participation and all data were obtained anonymously. Ethics approval was obtained from the Human Research Ethics Committee of The University of Western Australia.

The 2010 season was split into two main phases to match the training and game demands required of each period. During pre-season (November to mid-March), players performed ~3 field sessions, ~3 weights sessions, and several cross training and running conditioning sessions each week. Late pre-season saw a gradual reduction in field training loads with the introduction of pre-season practice games. In-season (mid-March to late-August) consisted of two weight sessions, one main field training session, with two lighter field sessions planned around the main session, followed by a game at the end of the week.

Intensity of training sessions and games were estimated by each player using the modified Borg CR-10 RPE scale[5] approximately 30 min following each session. Training and game load arbitrary units (AU) for each player were then derived by multiplying session-RPE by session/game duration (min). Measurements of blood lactate concentration and heart rate have correlated strongly with session-RPE in rugby league[6] and Australian football[14,15] training, suggesting that session-RPE is a valid method for quantifying training loads in team sports.

All injuries were categorised by the club's physiotherapist and defined as incidents resulting in a modified training program, missed training sessions or games. Injuries were classified as being low severity, resulting in training modification or 1–2 missed training sessions; moderate severity, where a player was unavailable for 1–2 games; or high severity, where a player missed 3+ games. Injuries were also categorised for injury type (description), body site (injury location) and intrinsic (internal; overuse, overexertion) or extrinsic (external; collision, contact) factors. The club's injury definition differs slightly from that of Orchard and Seward's,[3] in that all injuries, including those that limited a player's capacity to complete training, were taken into account in assessing a load/injury relationship.

Each day a player was involved in a training session or game, their previous 1, 2, 3 and 4 weekly individual loads were calculated. Relationships between training and game loads and injury were investigated in two ways. Firstly, the likelihood that an accumulation of load could contribute to an injury at a later date was considered by examining the link between 1, 2, 3 and 4 weekly cumulative loads and subsequent injury. Secondly, whether a large increment in load between weeks contributed to an injury was also explored. This involved analysing week-to-week change between the current and previous week's totals. Cumulative and absolute changes in load are further explained in Supplementary figs. A, B, C and D (online supplementary data). Load exposure values and injury data (injury vs. no injury) were then modelled in a logistic regression analysis. Data were divided into four groups, with the lowest training and game load range being the reference group. When an odds ratio (OR) was greater than 1, an increased odds of injury was reported. Conversely, when an OR was less than 1, a decreased odds of injury was reported. For an OR to be significant, 95% confidence intervals (CI) would not contain the null OR of 1.00.

Injury incidence was calculated by dividing total number of injuries by exposure time and reported as rates per 1000 training and game hours. Chi square analysis compared the frequency of injuries between pre-season and in-season periods. Differences in training and game loads between players of different AFL experience (1, 2–3, 4–6 and 7+ years) were analysed using a one-way ANOVA and group means compared using a Scheffé post hoc test. Data were analysed using IBM SPSS Statistics 20.0 and reported as means and 95% CI. Significance was accepted at $p < 0.05$.

3. Results

Additional data pertaining to classifications of pre-season and in-season injuries are provided in (online) Supplementary Table A.

Injury incidence increased ($\chi^2 = 9.37$, df = 1, $p = 0.002$) from pre-season (21.9 per 1000 h) to in-season (32.8 per 1000 h) (Supplementary Table B). The thigh (7.3 per 1000 h, 22.2%) and hip/groin (5.9 per 1000 h, 18.1%) were the most common sites of injuries in-season, with the most common types of injuries being muscle strains (10.7 per 1000 h, 32.6%) and haematomas/contusions (9.3 per 1000 h, 28.5%). Extrinsic injuries (18.9 per 1000 h, 57.6%) and intrinsic injuries (13.9 per 1000 h, 42.4%) were not different in rate of occurrence in-season.

Average field session loads decreased ($p < 0.001$) from pre-season (~151 AU) to in-season (~97 AU) (Table 1). Game loads from late pre-season practice matches (~642 AU) were significantly lower ($p < 0.001$) than in-season competition matches (~912 AU). Similarly, session-RPE intensity measures were lower in pre-season practice matches (~8.5) than in-season competition matches (~8.9), whereas field training intensities were lower in-season (~4.7) compared to pre-season (~5.3) sessions. Average individual weekly loads were greater ($p < 0.001$) in pre-season (~2027 AU) than in-season (~1651 AU). Injury incidence in-season was lowest for 1 year players (28.2 per 1000 h) and highest for 7+ year players (45.4 per 1000 h), however, no significant differences between groups were found (Table 1). Players with 7+ years of AFL experience completed significantly ($p < 0.01$) less load (~29,371 AU) in-season, compared to 2–3 (~40,788 AU) and 4–6 year (~40,238 AU) players.

Players who exerted 1 weekly loads in-season of >1750 AU were at significantly higher risk of injury compared to the reference group of <1250 AU (OR = 2.44, 95% CI 1.28–4.66, $p = 0.007$) (Table 2). Similarly, players who had completed a 2 weekly load in-season

Table 1
Load type per session for season phases, total training and game loads (arbitrary units) and injury incidence for different years of AFL experience. Data are mean (95% Confidence Intervals).

	Pre-season	In-season	Whole-season
Playing experience (y)	Injury incidence (per 1000 h)		
1 year ($n = 7$)	12.4 (0.0–27.8)	28.2 (17.3–39.1)	22.0 (15.1–28.8)
2–3 years ($n = 15$)	23.3 (13.9–32.7)	34.6 (24.2–44.9)	28.7 (21.8–35.6)
4–6 years ($n = 13$)	24.8 (13.9–35.8)	33.9 (22.9–45.0)	29.2 (19.9–38.5)
7+ years ($n = 11$)	25.4 (8.3–42.6)	45.4 (7.7–83.1)	31.8 (11.2–52.3)
	Training and game load (sum)		
1 year	23,475 (20,811–26,140)[*]	35,212 (32,201–38,223)	58,688 (53,399–63,976)[‡]
2–3 years	40,986 (38,541–43,430)	40,788 (37,705–43,872)	81,774 (76,693–86,855)
4–6 years	38,303 (34,714–41,891)	40,238 (37,603–42,873)	78,540 (73,522–83,559)
7+ years	33,611 (30,309–36,914)[**]	29,371 (23,764–34,978)[†]	62,982 (54,866–71,098)[‡]
Load type	Mean load per session		
Cross training	294 (286–301)[a]	241 (231–250)	276 (270–282)
Field	151 (147–155)[a]	97 (94–100)	125 (122–128)
Game	642 (612–617)	912 (898–925)[b]	856 (842–871)
Running conditioning	113 (110–117)	111 (104–117)	113 (110–116)
Weights	268 (266–271)[a]	231 (229–233)	250 (248–252)

Note: No significant differences were found between injury incidence in AFL years experience groups.
[*] 1 year ($p < 0.001$) significantly lower than 2–3, 4–6 and 7+ years.
[**] 7+ years ($p < 0.01$) significantly lower than 2–3 years.
[†] 7+ years ($p < 0.01$) significantly lower than 2–3 and 4–6 years.
[‡] 1 year and 7+ years ($p < 0.01$) significantly lower than 2–3 and 4–6 years.
[a] Pre-season ($p < 0.001$) significantly greater load than in-season.
[b] In-season ($p < 0.001$) significantly greater load than pre-season.

of >4000 AU were at significantly higher risk of injury compared to the reference group of <2000 AU (OR = 4.74, 95% CI 1.14–19.76, $p = 0.033$). Injury occurrence in-season was also higher for players who experienced a previous to current week change in load of >1250 AU (OR = 2.58, 95% CI 1.43–4.66, $p = 0.002$) compared to the reference group of <250 AU.

Players with 2–3 (OR = 0.22, 95% CI 0.07–0.68, $p = 0.009$) and 4–6 (OR = 0.28, 95% CI 0.10–0.82, $p = 0.020$) years of AFL experience were found to have a significantly lower risk of injury compared to 7+ year players when a previous to current week change in load was >1000 AU (Table 3). Interestingly, 1 year players had a significantly lower injury risk (OR = 0.39, 95% CI 0.16–0.93, $p = 0.035$) when compared to the 7+ year reference group when experiencing a 1 week load of >1650 AU.

Table 2
In-season training and game load risk factors for injury in elite Australian footballers.

Load calculation	In-season			
	OR	95% CI		*p*-Value
	Exp(B)	Lower	Upper	Sign.
Cumulative load (sum)				
1 week				
<1250 AU (reference)	1.00			
1250 AU to <1750 AU	1.95	0.98	3.85	0.056
1750 AU to <2250 AU	2.44	1.28	4.66	0.007
>2250 AU	3.38	1.69	6.75	0.001
2 weeks				
<2000 AU (reference)	1.00			
2000 AU to <3000 AU	2.98	0.70	12.66	0.138
3000 AU to <4000 AU	4.03	0.98	16.53	0.053
>4000 AU	4.74	1.14	19.76	0.033
Absolute change (±)				
Previous to current week				
<250 AU (reference)	1.00			
250 AU to <750 AU	1.34	0.90	2.01	0.148
750 AU to <1250 AU	0.89	0.50	1.58	0.680
>1250 AU	2.58	1.43	4.66	0.002

Note: No significant odds ratios were calculated in the pre-season phase.
OR, odds ratio; CI, confidence intervals.

4. Discussion

The purpose of this study was to examine whether a relationship existed between training and game loads and injury in AFL players. These results indicate injury risk is significantly higher for players who exert larger 1 (>1750 AU) and 2 weekly loads (>4000 AU) or a large previous to current week increment (>1250 AU) in comparison to lower training and game load ranges (<1250 AU, <2000 AU, <250 AU), respectively. These findings suggest that the training and game loads of elite Australian football players should be individually monitored on a weekly basis.

Non-contact and soft tissue intrinsic injuries are considered largely preventable, whereas contact and collision extrinsic injuries are considered generally unavoidable.[7] A range of intrinsic (42.4%) and extrinsic injuries (57.6%) were found during in-season. The inclusion of extrinsic injuries within this study is consistent with previous research[6,8] as Gabbett and Jenkins[16] reported training and game loads in professional rugby league to be strongly correlated

Table 3
AFL years experience risk factors for injury above certain training and game load values.

Load calculation	In-season			
	OR	95% CI		*p*-Value
	Exp(B)	Lower	Upper	Sign.
Cumulative load (sum)				
1 week				
>1650 AU				
7+ years (reference)	1.00			
1 year	0.39	0.16	0.93	0.035
2–3 years	0.74	0.43	1.25	0.258
4–6 years	0.67	0.38	1.17	0.160
Absolute change (±)				
Previous to current week				
>1000 AU				
7+ years (reference)	1.00			
1 year	0.14	0.02	1.13	0.065
2–3 years	0.22	0.07	0.68	0.009
4–6 years	0.28	0.10	0.82	0.020

Note: No significant odds ratios were calculated in the pre-season phase.
OR, odds ratio; CI, confidence intervals.

with contact injuries ($r = 0.80$, $p < 0.01$). However, intrinsic injuries are thought to be more directly linked with training and game loads.[7] A limitation of the injury classification within the present study was that recurrent or new injuries were not documented.

The risk of injury in-season for elite Australian footballers increased as the amount of 1 weekly load increased from the range of 1750 AU to <2250 AU (OR = 2.44) and >2250 AU (OR = 3.38) when compared to the reference group of <1250 AU. Gabbett and Domrow[6] also found significant relationships between 1-weekly training loads and injury risk in sub-elite rugby league players in early (OR = 2.85) and late (OR = 1.50) in-season periods.

As this study completed a rolling day-by-day analysis of training and game loads and injuries, it accounted for instances where two games were played within a 6-day period (e.g. Sunday game followed by a Saturday game). Injury rates of elite soccer players who played 2 matches within a week were significantly higher when compared to players involved in only 1 match.[17] Although this study analysed elite soccer players playing 2 matches within 4-days, our results suggest that AFL players participating in 2 matches within 6-days may be at an elevated risk of injury. However, more specific research on the turnaround time between matches and injury risk using a larger sample of teams is required.

After recovering from an injury, a player does not always have sufficient time to gradually increase their week-to-week training load prior to returning to large game loads. To our knowledge, this is the first study to highlight the importance of monitoring the week-to-week change in training and game loads. Players who exerted a previous to current week change in load of >1250 AU were found to be 2.58 times more likely to be injured in comparison to the reference group of <250 AU. Players returning from previous hamstring injuries have been shown to have a 9% chance of re-injury within the week of returning to matches.[18] A more conservative approach by gradually increasing the week-to-week training loads of previously injured AFL players, before large game loads occur, may result in a reduced chance of re-injury. Potentially, players returning from injury may benefit by being used as a substitute as a method to limit their initial game load and reduce injury risk.

During pre-season, no significant relationships between weekly or week-to-week changes of load and odds of injury were found. Similarly, no relationships were reported between average weekly pre-season training load and team injury incidence in elite rugby league[19] and AFL[11] players. However, in a study analysing the pre-season training loads and odds of injury of sub-elite rugby league players, an increase in log of training load (~150 AU) per week was found to significantly increase the odds of injury (OR = 2.12).[6] There is greater perceived control over the load exerted by elite players during pre-season, as session durations are usually planned by experienced conditioning staff and intensities are predicted by selecting activity/drill types (based on session-RPE averages). Players involved in this study would have had their pre-season training loads closely monitored and modified, which may have influenced the insignificant pre-season results found. Furthermore, the specific details of the training program of the AFL club involved within the study are currently unavailable for publication, as they are considered highly confidential.

Musculoskeletal immaturity of 1 year AFL players[12] was hypothesised here to cause an increased injury risk per training and game load, in comparison to 2–3 and 4–6 year players. However, no significant relationships were found between load derived values and injury risk. These results differ from a study reporting 1-weekly training loads to significantly relate to traumatic injuries in elite youth soccer players.[8] The in-season loads of the 1 year players within our study were highly monitored and modified, resulting in ~5000 AU lower loads compared to 2–3 and 4–6 year players. Due to the strict load modification strategy of 1 year players, they were not exposed to high weekly or week-to-week load changes and recorded the lowest in-season injury incidence (28.2/1000 h). Consequently, training and game load modification of immature first year players entering the elite system may be useful for preventing injuries. Reductions in pre-season training loads in sub-elite rugby league players have also been found to reduce injury rates.[20] The influence of pre-season training load on in-season injury risk in elite Australian footballers is an interesting concept which is yet to be examined.

The best starting 22 AFL players are generally older and more experienced[21] and frequently have accelerated returns from injury to full training and game loads, in an attempt to enhance team performance. Consequently, they are generally exposed to high week-to-week load increments. The 7+ year group had the largest in-season injury incidence (45.4 per 1000 h) and therefore completed significantly lower in-season loads (~6000–11,000 AU) compared to the less experienced groups. The injury risk of 2–3 (OR = 0.22) and 4–6 year players (OR = 0.28) was significantly lower than 7+ year players when experiencing a previous to current week change in load of >1000 AU. The body's ability to respond to rapid force changes or recover from fatigue has been speculated to slowly diminish as age and experience increases.[22] Therefore, care should be taken when exposing 7+ year players to a large previous to current week change in load. A confounding variable in the elevated odds of injury in more experienced AFL players is possibly previous injury history, as it has been reported as an independent predictor of subsequent hamstring injuries.[23] Future studies should analyse multiple seasons of data to more thoroughly investigate the effect of increasing experience on training and game loads and injury risk in AFL players.

Minimising injury risk is vitally important in elite team sports, as low injury rates can be critical to team performance.[24] However, training programs must elicit fitness improvements so that players are adequately prepared to endure the demands of competitive games. No fitness observations were made to analyse whether reductions in training load were detrimental to performance. Monitoring of global positioning system information (distance, sprint and accelerometer loads) and psychological data such as perceived muscle soreness, fatigue, mood, and sleep ratings,[18] may provide extra insight into injury risk relationships in elite Australian footballers.

5. Conclusion

During an elite Australian football in-season, larger 1 (>1750 AU) and 2 weekly loads (>4000 AU) and substantial previous to current week change in load (>1250 AU) were found to significantly increase injury risk when compared to lower training and game load ranges (<1250 AU, <2000 AU, <250 AU), respectively. As a method to reduce the risk of injury, derived training and game load values of weekly loads and previous week-to-week load changes should be monitored individually in elite Australian footballers.

Practical applications:

- The non-invasive and simple session-RPE method is useful for tracking training and game loads in respect to injury risk in elite Australian footballers.
- Weekly load sums and previous week-to-week changes in load should be monitored in-season for individual elite Australian footballers, as they are significantly related to injury risk.
- Training and game load modification strategies for first year AFL players may be important in achieving low injury incidence in their first season.
- Future in-season load management modifications could include planned reduction in training or game loads (especially by being the designated substitute, or player subbed out of game).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jsams.2012.12.004.

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