Repeated Exposure to Established High Risk Workload Scenarios Improves Non-Contact Injury Prediction in Elite Australian Footballers

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Abstract

Objectives: To assess the effect of multiple high risk scenario (HRS) exposures on non-contact injury prediction in elite Australian footballers.

Design: Retrospective cohort study.

Methods: Sessional workload data (session-rating of perceived exertion; GPS-derived distance, sprint distance, maximum velocity) from one club (n= 60 players) over 3 seasons were collated; several established HRS were also defined. Accumulated HRS sessional exposures were calculated retrospectively (previous 1-8 weeks). Non-contact injury data was documented. Univariate and multivariate Poisson regression models determined injury incidence rate ratios (IRR) while accounting for moderating effects (pre-season workload volume, playing experience). Model performance was evaluated using receiver operating characteristics (area under curve: AUC).

Results: Very low (0-8 sessions: IRR=5.76, 95% CI=1.69-19.66) and very high (>15 sessions: IRR=4.70, 95% CI=1.49-14.87) exposures to >85% of an individual's maximal velocity over the previous 8 weeks were associated with greater injury risk compared to moderate exposures (11-12 sessions), and displayed the best model performance (AUC=0.64). A single session corresponding to a very low chronic load condition over the previous week for all workload variables was associated with increased injury risk, with sprint distance (IRR=3.25, 95% CI=1.95-5.40) providing the most accurate prediction model (AUC=0.63).

Conclusions: Minimal exposure to high velocity efforts (maximum speed exposure, sprint volume) was associated with the greatest injury risk. Being under-loaded may be a mediator for non-contact injury in elite Australian football. Pre-season workload and playing experience were not moderators of this effect.

Keywords: injury risk; area under curve; high-velocity; team sports

Introduction

Australian football (AF) is a physical game involving large running volumes, rapid directional changes and high velocity running efforts. Minimising injury risk is a priority for sports medicine/science staff, as injuries have a detrimental impact on team and individual success.[1] An increased understanding of the relationship between workloads and injury has been recently established.[2-15] However, these studies have only evaluated a single exposure to high injury risk situations. In practice, athletes are repeatedly exposed to these situations as components of their training and competition schedules. Preliminary research has found a protective effect with the exposure to maximum velocity efforts in Gaelic football players,[10] suggesting both over- and under-exposure may be associated with increased injury risk. For the practitioner, these "high injury risk scenarios" (HRS) present challenges to the integrated high performance team[19 20] charged with managing the workload of athletes. Furthermore, factors such as aerobic fitness,[11] accumulated pre-season workload,[4 15] playing experience,[7 16] and previous injury[17] may also moderate the injury risk associated with these scenarios.

A consideration for sports medicine/science staff is determining the cost-benefit ratio[18] of injury risk decisions.[19 20] Here, the outcomes of the overall high performance system must be judged against sub-systems such as coaching needs and athlete health.[19] There is now level 1 evidence[1] to suggest that sacrificing an individual athlete's or the team's squad availability for matches will lower performance outcomes; therefore each decision must equally account for performance and health consequences. Predictive qualities (sensitivity, specificity, and receiver operating characteristics: ROC), in addition to relative and absolute risks associated with the data, may assist in this shared decision making process.[21] To date, only one study in AF has reported on subsequent week absolute injury risk changes (compared to baseline) for common workload metrics.[13] Here, an exposure to a high acute sprint load increased injury probability by 0.5% over the baseline exposure risk (pre-test probability). However, as highlighted recently,[22] the minimal important difference for these absolute risks before targeted (indicated) prevention occurs is subject to the views of players, coaches and/or practitioners, and is context specific.

To date, most research has assessed injury risk as a "one-off" exposure at a given time point (i.e. start of a week[5]) or latent period.[14] Yet, in practice, athletes may be repeatedly exposed to these potential high-risk injury situations. Therefore, this study seeks to inform practitioners in three ways: a) detail how multiple exposures to established HRS increase injury risk; b) determine if a player's pre-season workload exposure and playing experience moderates the HRS and injury relationship; c) determine the clinical utility of these results in a real world setting. We hypothesised that greater exposure to established HRS would be associated with increased injury risk, and that this relationship would be moderated by pre-season workload and playing experience.

Methods

Player data (n=60: 46 players were listed in multiple seasons) from a single Australian Football League (AFL) club across three consecutive seasons (2014-2016) was used. In total, 7147 individual in-season sessional data points were collected. Mean (± SD) player age, stature and body mass were: 23.3 ± 3.8 y, 188.9 ± 6.4 cm and 88.1 ± 7.9 kg, respectively. For AFL system experience, 27% of players had 1-2 y, 27% had 3-6 y and 46% had 7+ y, respectively. Players either competed in AFL or Western Australian Football League matches across these seasons. All players provided written consent prior to participation. Data was de-identified and extracted from the club's athlete management system (SMARTABASE, Fusion Sport, Brisbane, Australia). Human ethics approval was obtained from the host institution review board (approval RA/4/1/5015).

Injury information was classified and collated by the club's senior physiotherapist. As per previous research[5], only lower body non-contact injury resulting in matches missed were included. This definition of injury is comparable to a competition, sports incapacity injury.[23,24]

Previously validated objective (GPS-derived; total distance, sprint distance, maximal velocity) and subjective (field on-legs sRPE) sessional workload data was collated throughout each season, as per prior research.[5] Using the evidence-base of previous literature, several HRS were defined (Table 1). Sessions where athletes were exposed to a HRS were summed for several retrospective timeframes (i.e., previous 1-8 weeks of training) prior to every session. It should be noted that the traditional acute:chronic workload ratio was used (to match previous investigations within this cohort[5]), however, recent investigations have suggested caution should be exercised with this method due to mathematical coupling.[25]

Insert Table 1 about here

A mixed model generalized estimating equation (GEE) analysed the relationship between sessional data and injury, as these analyses can handle panel data (repeated individual measures). For injury risk (injury/no injury in any session), a Poisson log-link regression with robust error estimate, and exchangeable working correlation structure (within the GEE model) was used.[26] To determine if multiple exposures to HRS increased or decreased non-contact injury risk, incidence rate ratios (IRR) were calculated for above (high risk) and below (low risk) the cut-point, thereby maximising sensitivity and specificity (Youden's index). Maximum velocity counts were sorted from lowest to highest and split into pentiles for analysis to represent very-low to very-high ranges, as quadratic relationships for this variable has been observed previously.[10] Univariate GEE regression models for each predictor variable were determined, not accounting for other moderating covariates.[5 27] As playing experience[16] and pre-season workload[4 15] have both been previously associated with injury, these variables were entered into a multivariate model (as pentiles) to determine if the risks associated with HRS exposures were moderated.[27] Adjusted IRR (adj-IRR) in the multivariate models represent the risk whilst accounting for moderating effects of other variables.[5] All data analysis was performed in Stata 12 (Stata 12 IC, StataCorp, USA). Statistical significance occurred when an IRR 95% CI did not cross 1.00. Clinical significance was determined if the IRR was greater than 3.0.

The ROC curves were then used to assess the accuracy of predicted probability from each model, with AUC comparisons to determine the best timeframe undertaken using the "jack-knife method" (a nonparametric estimate for variance comparisons[28]), with Sidak correction to account for multiple comparisons. When no significant difference occurred between timeframes, the most practical (shortest) timeframe in a real-world setting was presented. Furthermore, to evaluate each model's ability to fit out-of-sample data, *k*-fold cross-validation with 10-folds was utilized. For comparison, root mean squared error (RMSE) was reported where lower values and less variability (SD: standard deviation) between *k*-folds indicated a better fit. To determine the clinical utility of risk factors, pre- and post-test probabilities were calculated and the difference (absolute risk) presented. Injured players' data for the sessions following injury were excluded until they returned to main training.

Results

Overall, 58 non-contact lower body injuries resulting in games missed were sustained across the three in-season phases and were subsequently included in the analysis. Descriptive statistics and very low/very high cut-points for workload variables are presented in supplementary online material (Table A).

Table 2 presents the univariate models. If no significant differences existed between the AUC, the most practical (shortest) timeframe of exposures are presented. For the high-risk scenarios presented (Table 2), sensitivity and specificity of each exposure range can be found in online supplementary material (Table B).

Insert Table 2 about here

An increase in the positive predictive value was observed for lower pre-season (GPS) workloads, greater playing experience and increased injury risk; however, the model accuracy was poor (AUC=0.54-0.59) and the IRR 95% CI crossed 1.0 (online supplementary material; Table C). These hypothesised moderators, when included in a multivariate model, did not alter the IRR associated with the HRS. Nor did they significantly improve in-sample (AUC) or out-of-sample (RMSE) model accuracy. As such, the results are not presented here.

The pre-test probability of sustaining a non-contact lower limb injury was 0.81% per day. To display the daily predictive properties of each variable, absolute risk (post-test probability – pre-test probability) is presented in Table 2.

When variables were modelled on unseen data (cross validated), RMSE values for all variables were similar (0.09 ± 0.02 SD), suggesting these variables had a similar ability to fit out-of-sample data. As such, the results are not presented here.

A practical guide for optimal maximum speed exposures over a 4-week timeframe is presented in Figure 1.

Insert Figure 1 about here

Discussion

To our knowledge, this is the first study to investigate multiple exposures to high-risk loading conditions and non-contact injury risk in elite AF. Prior research[3 5 12-14] has investigated injury risk associated with single exposures to high-risk loading conditions in AF; however, our data shows that greater risk may be associated with multiple exposures (which commonly occurs) over varying timeframes. The HRS pertaining to high velocity exposure (maximum speed exposure, sprint chronic volume) displayed the greatest relative risks and injury predictive accuracy. For these scenarios, under-load (i.e. a low chronic load, low maximum speed exposure) recorded the greatest association with injury risk, potentially reflecting a state of under-preparedness. For this cohort, minimal exposure to maximum velocity efforts and having a low chronic load condition may be a key mediator for non-contact injury.

A U-shaped relationship was evident for repeated sessional exposure to near maximal velocities and non-contact injury risk (Figure 1). Very low exposures identified the greatest number of injuries (49%). Previous research[10] has investigated exposure to maximum velocity efforts in Gaelic football players, but did not assess timeframes greater than the previous 7-days, nor the predictive accuracy. Our findings suggest exposures over longer timeframes (4-8 weeks) improve predictive accuracy. Targeted (indicated) injury prevention strategies in AF should include exposure to >85% of an individual's maximum velocity over 5-8 sessions (training or games) across a 4-week block, as this velocity threshold displayed the greatest predictive accuracy (AUC_{range} = 0.60-0.64).

A repeated exposure effect for on-legs sRPE very low (<3623 AU) chronic workloads in the past week was observed. Subjective measures of workload may be more sensitive at predicting non-contact injury when a very low load 'trough' of two or more sessions is observed. Furthermore, multiple exposures (3 or more) to a very high (>1.37) on-legs sRPE ACWR over the previous 2-weeks was associated with greater injury risk compared to less than three exposures; although sensitivity (22% of injuries above threshold) and predictive accuracy were poor (AUC= 0.55). Potentially, players eliciting a very high ACWR in a session increase their chronic load to a point that does not allow for a very high ACWR in subsequent sessions, possibly explaining the lack of findings here. Lastly, multiple exposures (3 or more sessions) to large week-to-week changes (on legs sRPE >20%, distance >30%) over the previous 2-weeks increased injury risk but also displayed poor predictive accuracy (AUC=0.55-0.56). Despite a low sensitivity (21-22%) to predict injury when classified as high risk, the number of "false alarms" (specificity=87-90%) was notably lower than other variables, suggesting practitioners should still consider acting when these scenarios occur. If a player enters a high risk condition, such as those identified above, an 'indicated'[29] (targeted) prevention approach should attempt to minimize subsequent exposures within the following 2-week block.

For objective workload measures, as little as one sessional exposure to a very low chronic (distance <75 141 m, sprint <599 m) or acute (sprint <118 m) load condition in the past week increased injury risk. Notably, exposure to a very low sprint chronic load condition in the previous week was associated with a 3-fold increase in injury risk, identifying 50% of injuries in this cohort. As such, preventive strategies should ensure AF players attain >150 m of sprint volume per week, to maintain a minimum workload for competitive demands.[2] Practitioners may also take a selective prevention approach[29] for players forecasted to fall into a very low acute or chronic load conditions in subsequent sessions (forecasted sessions may be calculated through a training drill and/or game average database). Suggested approaches may include; a) informing the player of their low output prior to training and the need for greater exertion in training drills; b) modifying drills within training to allow greater output for the required (low) load variables; c) prescribing running conditioning drills to allow players to attain the required volume.

It was hypothesized here that playing experience would be a moderating factor in significantly decreasing the IRR associated with HRS. However, as reported recently,[7] there was no evidence to suggest playing experience significantly moderated the HRS defined here. Greater pre-season volume has also been shown to reduce in-season injury risk in this cohort[4], however, no moderating effect was observed when accounted for in a multivariate model. These findings may be explained by the modelling approach undertaken here. Firstly, HRS were defined prior to considering any interaction effects. Therefore, HRS may vary depending on years of playing experience. Secondly, the "optimal" cut point (that maximized sensitivity and specificity) was determined for the full squad. Creating exposure cut points by playing experience and/or pre-season workload may provide greater insight.

As discussed in a recent editorial,[21] it is important to differentiate between association (i.e. incidence risk ratios) and prediction (i.e. sensitivity, specificity, AUC) when advising coaches on the injury risk for various loading conditions. Further to these suggestions, we believe comparing HRS to the baseline exposure risk (or pre-test probability) of playing the sport/being on the field will give practitioners further insight into the absolute risk in applied settings. The absolute risk (or risk difference[22]) is calculated by subtracting the post-test probability (probability after being classified within a loading condition) from the pre-test probability (probability of getting injured within the total sample). When interpreting absolute risks, it is important to consider the setting in which they are calculated; for example, daily/sessional, weekly, or training phase. For this study, absolute risks were unsurprisingly low since the 'event' (i.e., non-contact injury resulting in a match missed) was rare and data was analyzed on a sessional basis. Previous research[13] has reported a *weekly* absolute risk of 0.5% for incurring a subsequent week hamstring injury strain when exposed to >653m of high intensity running. Our results identified a slightly higher absolute risk (0.37-1.01%), even when calculated on a *sessional* basis, with a very low chronic load (sprint, on-legs sRPE) and large week-to-week changes (multiple exposures >20% on-legs sRPE) displaying the greatest absolute risk. Although this study did not seek to establish the minimal important difference[22] from the absolute risks presented, it is important coaches are informed and make injury risk decisions in a context-specific manner.

Lastly, some study limitations should be acknowledged. Firstly, a relatively low number of injuries were included (and therefore the chance of detecting an injury event was rare, being <1%), as the study focused on injuries most detrimental to performance (matches missed). Accounting for the interplay between all injuries (i.e. low severity and/or high impact contact injuries) may improve injury detection, as preliminary evidence suggests subsequent injuries are usually related to an initial/previous injury.[17] Secondly, as a retrospective study design was employed to include all available workload data up to a given session, the injury lag period (i.e. subsequent week) was excluded. Future research may adopt a prospective epidemiological approach that examines the multiplicative injury risk of each subsequent exposure to a HRS and injury in a given lag period. Thirdly, staff at the AFL club used here were aware of current literature, and as such, likely made decisions to mitigate risk (i.e. training load management) when athletes were exposed to a HRS (i.e. an ACWR > 1.50). By auditing injury risk actions and decisions, practitioners may further validate these metrics for injury prediction in prospective seasons. Fourthly, the HRS defined here were taken from previous literature and case studies specific to this cohort. Future research should examine the HRS specific to a particular sport. Finally, this modelling approach examined the total sum of sessions exposed in each timeframe, and did not account for the distribution of these exposures. Further research should determine if consecutive or exponentially weighted exposures increase injury risk.

Conclusions

A U-shaped relationship between maximum speed exposure and increased injury risk was evident in AF. Low maximum speed exposure and low chronic workloads were identified as HRS. Multiple exposures to HRS may be required before non-contact injury detection is optimized. Very low daily absolute lower limb injury risk was observed. Being under-loaded, may be a mediator for non-contact injury in elite Australian football.

Practical Implications

- Implementing a maximum velocity "top-up" training protocol to ensure athletes are exposed to near maximal speeds on a regular basis may reduce injury risk.
- Establishing a chronic load 'floor' may reduce injury risk by ensuring players are well prepared for the demands of competition.
- Targeted injury prevention strategies in AF should involve forecasting loads to monitor players who are trending towards very low loading conditions.

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Table 1. Quantification of high risk scenarios and supporting literature.

High risk scenario	Calculation	Supporting literature
	Count of sessions exposed for the past "n" weeks	
Over-load/ Non-functional over-reaching		
ACWR spike	Very high ACWR as determined by sessions categorized in the 5th quantile	5, 8, 9, 14
Week-to-week change	Previous (2-weeks ago) to current week (last 7 days) change >10, 20, 30%	6, 12
Very high chronic load	Very high 4-week chronic load as determined by sessions categorized in the 5th quantile	3, 12
Acute workload ceiling	Individual's highest 1-week acute load for the current season	2
Chronic workload ceiling	Individual's highest 4-week chronic load for the current season	2
Season high maximal velocity	Individual's new maximum speed for that season	Novel - "PB effect"
Under-load/ Ill-prepared for competitive demands		
ACWR trough	Very low ACWR as determined by sessions categorized in the 1st quantile	5
Very low chronic load	Very low 4-week chronic load as determined by sessions categorized in the 1st quantile	5
Exposure to maximal velocity	Session with at least one effort > 80, 85, 90, 95% of their historical maximum speed to date	10
Potential moderators		
AFL system playing experience	3 quantiles to represent a developing, main squad or veteran athlete	5, 16
Pre-season workload	3 quantiles to represent low, moderate, and high total pre-season workload	4, 15

"n" = 1-8 weeks; ACWR = acute:chronic workload ratio; AFL = Australian Football League

Table 2 Univariate models: High risk scenario exposures and non-contact injury risk.

High risk scenario		TIMEFRAME: Sessions Exposed	PPV [%]	IRR (95% CI)	Absolute Risk	AUC (95% CI)
EXPOSURE TO MAX SPEED						
> 85 % individual max		**LAST 8-WEEKS:**				
	Very Low	0 - 8	1.32	**5.76 (1.69-19.66)**	0.55%	
	Low	9	0.58	2.58 (0.69- 9.64)	-0.19%	
Most significant	*Moderate*	11 – 12 (ref)	0.21	1.00	-0.55%	0.64 (0.58-0.71)
	High	13 - 15	0.66	**3.03 (1.01 - 9.10)**	-0.11%	
	Very High	> 15	1.03	**4.70 (1.49 – 14.87)**	0.26%	
> 85 % individual max		**LAST 4-WEEKS:**				
	Very Low	0 - 4	1.18	2.15 (0.97-4.79)	0.41%	
	Low	5	0.49	0.93 (0.33- 2.59)	-0.28%	
Most practical	*Moderate*	6 (ref)	0.52	1.00	-0.25%	0.60 (0.53 - 0.68)
	High	7 - 8	0.55	1.05 (0.46- 2.42)	-0.22%	
	Very High	9 - 12	0.87	1.64 (0.62 – 4.31)	0.10%	
VERY LOW 4-WEEK CHRONIC LOAD						
Sprint distance chronic < 599 m		**LAST 1-WEEK:**				
	Low Risk	0 (ref)	0.54	1.00	-0.27%	0.63 (0.56-0.69)
	High Risk	≥ 1	1.64	**3.25 (1.95- 5.40)**	0.83%	
On Legs sRPE chronic < 3623 AU		**LAST 1-WEEK:**				
	Low Risk	< 2 (ref)	0.63	1.00	-0.18%	0.59 (0.53-0.65)
	High Risk	≥ 2	1.63	2.52 (1.51- 4.19)	0.82%	
Distance chronic < 75 141 m		**LAST 1-WEEK:**				
	Low Risk	0 (ref)	0.66	1.00	-0.15%	0.57 (0.50-0.63)
	High Risk	≥ 1	1.18	1.71 (1.09- 2.66)	0.37%	
VERY LOW 1-WEEK ACUTE LOAD						
Sprint Distance < 118 m		**LAST 1-WEEK:**				
	Low Risk	0 (ref)	0.60	1.00	-0.21%	0.59 (0.52-0.65)
	High Risk	≥ 1	1.24	2.04 (1.24- 3.38)	0.43%	
VERY HIGH ACWR						
On Legs sRPE > 1.37		**LAST 2-WEEKS:**				
	Low Risk	< 3 (ref)	0.63	1.00	-0.08%	
	High Risk	≥ 3	1.16	1.93 (1.13- 3.31)	0.65%	0.55 (0.49-0.60)
LARGE WEEK-TO-WEEK CHANGE						
On Legs sRPE > 20%		**LAST 2-WEEKS**:				
	Low Risk	< 4 (ref)	0.70	1.00	-0.11%	0.56 (0.51-0.62)
	High Risk	≥ 4	1.82	2.53 (1.38- 4.63)	1.01%	
Distance > 30%		**LAST 2-WEEKS:**				
	Low Risk	< 3 (ref)	0.72	1.00	-0.09%	0.55 (0.49-0.60)
	High Risk	≥ 3	1.38	1.85 (1.02- 3.35)	0.57%	

PPV = positive predictive value (injured cases/ total cases *100); IRR = incidence rate ratio; CI = confidence interval; SD = standard deviation; AUC = area under curve; ref = reference category; ACWR = acute:chronic workload ratio; On Legs sRPE= field session rating of perceived exertion
Note, high risk scenario's where IRR >3.00 (clinical significance) appear in bold.

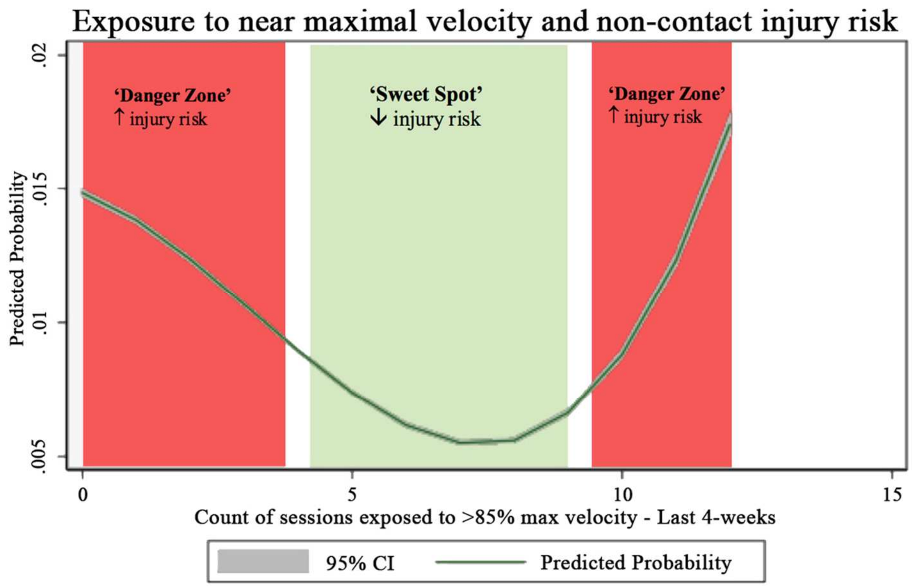

Figure 1. Predicted injury probability for the most practical maximum speed exposure model. A U-shaped relationship for the number of sessions exposed to near maximal velocity and non- contact injury risk is evident. To minimize injury risk, athletes should aim to elicit greater than 85% of their maximum velocity in 5-8 sessions over a 4-week period.

108x68mm (300 x 300 DPI)

Online Supplementary Material

Table A. In-season workload averages across all seasons.

		2014	2015	2016	Combined seasons	Very low load	Very high load
		Mean load per session (±SD)					
Distance (m)							
	1-week acute load	22996 ± 5679	23017 ± 5636	22934 ± 4819	22981 ± 5382	< 18937	> 26773
	4-week chronic load	85816 ± 12841	83925 ± 12387	83756 ± 10643	84482 ± 12004	< 75141	> 94187
	Acute:chronic workload ratio	1.08 ± 0.29	1.10 ± 0.25	1.10 ± 0.21	1.09 ± 0.25	< 0.93	> 1.26
	Week-to-week change	1 ± 45	3 ± 47	6 ± 42	3 ± 45	-	-
Sprint Distance (m)							
	1-week acute load	282 ± 165	256 ± 170	253 ± 157	263 ± 164	< 118	> 391
	4-week chronic load	1038 ± 411	938 ± 448	932 ± 412	969 ± 426	< 599	> 1337
	Acute:chronic workload ratio	1.09 ± 0.51	1.10 ± 0.56	1.08 ± 0.49	1.09 ± 0.52	< 0.66	> 1.48
	Week-to-week change	-63 ± 516	-116 ± 1143	-38 ± 242	-71 ± 733	-	-
On Legs sRPE (AU)							
	1-week acute load	1279 ± 517	1199 ± 553	1205 ± 499	1227 ± 524	< 703	> 1526
	4-week chronic load	4669 ± 1164	4335 ± 1183	4460 ± 946	4487 ± 1108	< 3623	> 5400
	Acute:chronic workload ratio	1.11 ± 0.42	1.11 ± 0.44	1.08 ± 0.39	1.10 ± 0.41	< 0.84	> 1.37
	Week-to-week change	-17 ± 161	-32 ± 209	-37 ± 252	-29 ± 212	-	-
Max Velocity (km/h)							
	Session load	27.1 ± 3.2	26.9 ± 3.1	27.4 ± 3.0	27.1 ± 3.1	-	-

m = metres; AU = arbitrary unit; km/h = kilometres per hour; SD = standard deviation; Acute:chronic workload ratio = 1 week/average 4 week values
Very low load = 1st quantile (lowest); Very high load = 5th quantile (highest)
On Legs sRPE= field session rating of perceived exertion

Table B. Predictive features: High risk scenario exposures and non-contact injury risk.

High risk scenario			TIMEFRAME: Sessions Exposed	Sensitivity	Specificity
EXPOSURE TO MAX SPEED					
> 85 % individual max			**LAST 8-WEEKS:**		
		Very Low	0 – 8	0.42	0.76
		Low	9	0.13	0.83
	Most significant	*Moderate*	11 – 12 (ref)	0.05	0.80
		High	13 – 15	0.22	0.74
		Very High	> 15	0.18	0.86
> 85 % individual max			**LAST 4-WEEKS:**		
		Very Low	0 – 4	0.49	0.68
		Low	5	0.11	0.83
	Most practical	*Moderate*	6 (ref)	0.11	0.84
		High	7 – 8	0.18	0.75
		Very High	9 – 12	0.11	0.90
VERY LOW 4-WEEK CHRONIC LOAD					
Sprint distance chronic < 599 m			**LAST 1-WEEK:**		
		Low Risk	0 (ref)	0.50	0.24
		High Risk	≥ 1	0.50	0.76
On Legs sRPE chronic < 3623 AU			**LAST 1-WEEK:**		
		Low Risk	< 2 (ref)	0.64	0.18
		High Risk	≥ 2	0.36	0.82
Distance chronic < 75 141 m			**LAST 1-WEEK:**		
		Low Risk	0 (ref)	0.59	0.28
		High Risk	≥ 1	0.41	0.72
VERY LOW 1-WEEK ACUTE LOAD					
Sprint Distance < 118 m			**LAST 1-WEEK:**		
		Low Risk	0 (ref)	0.50	0.33
		High Risk	≥ 1	0.50	0.67
VERY HIGH ACWR					
On Legs sRPE > 1.37			**LAST 2-WEEKS:**		
		Low Risk	< 3 (ref)	0.79	0.11
		High Risk	≥ 3	0.21	0.89
LARGE WEEK-TO-WEEK CHANGE					
On Legs sRPE > 20%			**LAST 2-WEEKS:**		
		Low Risk	< 4 (ref)	0.78	0.10
		High Risk	≥ 4	0.22	0.90
Distance > 30%			**LAST 2-WEEKS:**		
		Low Risk	< 3 (ref)	0.78	0.13
		High Risk	≥ 3	0.22	0.87

ACWR = acute:chronic workload ratio;On Legs sRPE= field session rating of perceived exertion

Table C. Univariate models: Hypothesized moderators and non-contact injury risk.

High risk scenario	Range	PPV [%]	IRR (95% CI)	Absolute Risk	AUC (95% CI)
PRE-SEASON LOAD EXPOSURE					
Cumulative Distance					
Very Low	0 - 324 km	0.76	0.93 (0.43- 1.98)	-0.05%	
Low	324 – 364 km	1.05	1.36 (0.60- 3.06)	0.24%	
Moderate	364 - 393 km	0.62	0.85 (0.36- 2.01)	-0.19%	0.55 (0.48-0.62)
High	393 – 434 km	0.86	1.01 (0.48- 2.55)	0.05%	
Very High	> 444 km (ref)	0.77	1.00	-0.04%	
Cumulative Sprint Distance					
Very Low	0 - 2462 m	1.11	2.17 (0.86- 5.52)	0.30%	
Low	2462 – 3327 m	1.05	2.07 (0.80- 5.33)	0.24%	
Moderate	3327 - 4524 m	0.81	1.59 (0.62- 4.09)	0.00%	0.58 (0.51-0.65)
High	4524 – 5517 m	0.57	1.13 (0.42- 3.05)	-0.24%	
Very High	> 5517 m (ref)	0.50	1.00	-0.31%	
Cumulative On-Legs sRPE					
Very Low	0 - 12429 AU	0.74	0.93 (0.46- 1.90)	-0.07%	
Low	12429 – 14223 AU	1.20	1.54 (0.78- 3.07)	0.39%	
Moderate	14223 - 15984 AU	0.92	1.25 (0.55- 2.84)	0.26%	0.59 (0.51-0.66)
High	15984 – 17158 AU	0.42	0.59 (0.19- 1.85)	-0.39%	
Very High	> 17158 AU (ref)	0.78	1.00	-0.21%	
PLAYING EXPERIENCE					
Very Low	1 - 2 years (ref)	0.72	1.00	-0.05%	
Low	3 - 4 years	0.73	1.00 (0.36 - 2.82)	-0.04%	
Moderate	5 - 7 years	0.68	0.96 (0.47 – 1.98)	-0.09%	0.54 (0.46-0.62)
High	8 - 9 years	0.71	1.03 (0.50 - 2.10)	-0.06%	
Very High	> 10 years	1.08	1.51 (0.63 – 3.66)	0.31%	

PPV = positive predictive value (injured cases/ total cases *100); IRR = incidence rate ratio; CI = confidence interval; SD = standard deviation; AUC = area under curve; ref = reference category; ACWR = acute:chronic workload ratio; On Legs sRPE= field session rating of perceived exertion