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Identifying high risk loading conditions for in-season injury in elite Australian football players

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Abstract

Objectives: To examine different timeframes for calculating acute to chronic workload ratio (ACWR) and whether this variable is associated with intrinsic injury risk in elite Australian football players.

Design: Prospective cohort study

Methods: Internal (session rating of perceived exertion: sRPE) and external (GPS distance and sprint distance) workload and injury data were collected from 70 players from one AFL club over 4 seasons. Various acute (1-2 weeks) and chronic (3-8 weeks) timeframes were used to calculate ACWRs: these and chronic load categories were then analysed to determine the injury risk in the subsequent month. Poisson regression with robust errors within a generalised estimating equation were utilised to determine incidence rate ratios (IRR).

Results: Altering acute and/or chronic timeframes did not improve the ability to detect high injury risk conditions above the commonly used 1:4 week ACWR. Twenty-seven ACWR/chronic load combinations were found to be "high risk conditions" (IRR>1, $p<0.05$) for injury within 7 days. Most (93%) of these conditions occurred when chronic load was low or very low and ACWR was either low (<0.6) or high (>1.5). Once a high injury risk condition was entered, the elevated risk persisted for up to 28 days.

Conclusions: Injury risk was greatest when chronic load was low and ACWR was either low or high. This heightened risk remained for up to 4 weeks. There was no improvement in the ability to identify high injury risk situations by altering acute or chronic time periods from 1:4 weeks.

Keywords: training load, injury, acute:chronic workload ratio, Australian football, Global positioning system

Introduction

Injuries are a common obstacle to team sport success.[1] The aetiology of sports injury is multi-factorial, with characteristics such as age,[2] injury history,[3] strength,[4] fitness[5] and training background[6] being important factors.[7] Controlling known risk factors is vital for injury prevention, and encompasses risk stratification into universal, selective and indicated risk.[8] One risk factor of particular interest to sports medicine/science staff is training load, which may influence all three risk types.[7]

A "ceiling of safety"[7] for workload has been observed for team sports, with both high internal (e.g. session rating of perceived exertion: sRPE)[9] and external (e.g. GPS metrics)[10] loads relating to increased injury risk. In addition to this, low workloads have also been identified as an injury risk factor. Studies in both rugby union[11] and cricket[12] have reported a "U-shaped" relationship exists between workload and injury suggesting an optimal load range may exist for injury prevention. Consequently, the concept of low and high physical workloads being protective or detrimental to injury risk has been suggested, and described as the training-injury prevention paradox.

In addition to using absolute workload methods, the potential value of relative workloads in assessing injury likelihood has been recently demonstrated.[13-15] Metrics such as the acute:chronic workload ratio (ACWR) can provide a more comprehensive assessment of training load as acute loads (1 week) are expressed relative to chronic loads completed over a greater timeframe (3+ weeks). Hulin and colleagues[13] demonstrated that elite fast bowlers with an ACWR (1 week rolling total load versus 4 week rolling total load averaged to 1 week) >200% (ACWR: 2.0) were 4.5 times more likely to get injured than if ACWR was between 50-100%. Blanch and Gabbett[16] combined data from 3 team sports, reporting a quadratic relationship ($R^2 = 0.53$) between ACWR (1 week to 4 week) and injury likelihood, suggesting (as with absolute loads) an optimal range for ACWR to minimise injury risk. Further, ACWR has been shown to interact with absolute workload, whereby a high ACWR (1 week to 4 week) combined with a high chronic (4 weeks) load resulted in the greatest injury risk from a number of different load conditions studied.[15] However, a moderate ACWR combined with a high chronic load reduced risk compared to a number of AWCR conditions when chronic load was low.[15] These novel findings indicate that both ACWR and chronic load should be carefully managed by sport science/medicine staff. Further, the heightened risk following poor management of these loads can persist for 3-4 weeks.[17]

To date, the majority of investigations of ACWR have used arbitrary timeframes of 1 and 4 weeks for acute and chronic loads respectively. A recent study[18] examined the efficacy of daily ACWRs derived from a number of timeframes for GPS load variables in explaining injury likelihood. A 3-day or 6-day acute load period expressed relative to a 21-day chronic load for moderate speed running was reported to explain injury risk better than the other ratios examined. However, the study did not consider the interaction effect with chronic load and used the R-squared statistic (a model fit diagnostic) to determine each variable's ability to explain injury risk. While this study provided useful insight into which ACWRs best fit the quadratic relationship identified by Blanch & Gabbett, further statistical analysis is required to quantify the risk of different ACWR timeframes for clinical utility[19]. Therefore, this study aimed to; (1) determine the most clinically useful ACWR windows for the identification of high risk scenarios using various acute and chronic timeframes; (2) identify load variable combinations associated with elevated injury risk; (3) determine the duration of any increased risk (latent period).

Methods

In-season data (including pre-season matches) was prospectively collected from Australian footballers (n=70: mean ± SD age 22.9 ± 3.4 years) from one AFL club who were contracted in the 2012 (n=46), 2013 (n=44), 2014 (n=44), and 2015 (n=45) seasons. A total of 4131 individual weekly data points were collected. Players were categorised by AFL experience as development (1-2 years), main group (3-6 years) and veteran (7+ years); each category made up 23%, 39% and 38% of the dataset, respectively. All participants provided written consent prior to participation and all data was de-identified before extraction from the club's database. Ethical approval was obtained from the Human

Research Ethics Committee (RA/4/1/5015) of The University of Western Australia and complies with [20]the Declaration of Helsinki.

Both internal (subjective[21]) and external (GPS[22, 23]) validated workload measures were collected. Internal workload was measured using the sRPE method, where load (arbitrary units) is the product of the 10-point modified-Borg scale[21] and session duration. This was only collected for field training sessions. Multiple external loads (SPI Pro X, GPSports, Canberra, Australia; 5 Hz, interpolated to approximate 15 Hz) were quantified. “Distance” was defined as total distance covered (m) and “sprint distance” as total distance covered (m) above 75% of the individual player’s maximum speed (determined from preseason 20m test (electronic timing gates, Fusion Sport, Brisbane) or GPS game data). The GPS units used have previously been demonstrated to be reliable in measuring such variables[20]. Distance and sprint distance were taken directly from GPSports (TEAM AMS—release 1.9 2012) software.

Chronic training load (CTL) variables were calculated weekly for each of the four load metrics by averaging the weekly load over the respective timeframe (3-8 weeks). Weekly data was defined by the period between Monday and Sunday of each week. Various ACWR were calculated by dividing an acute load (average weekly load over 1 or 2 weeks) by CTL (3-8 weeks).[13, 15] To avoid extreme ACWR resulting from abnormally low CTL (e.g., players returning from injury), CTL values below a z-score of -2 were removed from analysis.[15] Subsequently, ACWR between 0 and 2.1 were binned into 0.3 unit categories, with extremely high values (2.1-3.0) combined into one bin due to the low number of cases. The dataset was further binned by quartile groups (very low/low/high/very high) for each chronic load variable.

Injury information was classified by the club’s senior physiotherapist.[10] Only intrinsic (non-contact) injury resulting in one or more matches being missed (sports incapacity[24]) were included, as such injuries have previously been related to training load.[6]

Injury incidence in each ACWR/CTL category was determined, then variables were compared based on their value in predicting injury within the week, to assess the best timeframes and ratios. After identifying risk conditions, assessment of the latent period (where injury risk was significantly higher compared to baseline, across periods of 7, 14, 21 and 28 days) was made. To ensure that risk was not compounded across latent periods, a player's data for a given week was excluded from this analysis following an injury. All statistical analyses were undertaken in Stata 12 (Stata 12 IC, StataCorp, USA), with significance set at $p<0.05$.

As a retrospective cohort design was used, incidence rate ratios (IRR) were calculated.[25] A mixed-model generalized estimating equation (GEE) was used to investigate the relationship between load and injury, as these analyses can handle panel data (repeated individual measures). For injury risk (yes/no in any week), a Poisson log-link regression with robust error variance (within the GEE model) was used.[25] These regression models were fitted for each ACWR for each load variable. Given the previously demonstrated interaction between ACWR and absolute load,[15] the chronic load corresponding to that in the ACWR was included in the model as an interaction effect. Age and experience category were included as covariates within the panel data set for each individual. Each model then produced a probabilistic injury model for each data point. Receiver Operator Characteristic (ROC) curves then assessed each model's predicted probability accuracy. Area under the curve (AUC) comparisons for each variable were undertaken using the "jack-knife method" (a nonparametric estimate for variance comparisons[26]), with Sidak correction to account for multiple comparisons. Variables with the greatest significant improvement in AUC compared to the traditional 1 week to 4 week ACWR were retained for further analysis. When no variable offered improvement on the traditional ratio, the 1 week to 4 week ACWR was retained.

For the selected variables, IRRs for injury within 7 days for each load category were produced. The ACWR bin of 90-120%, combined with the high chronic load quartile, was selected as the reference category, as this was hypothesised to be the lowest risk category, based on previous research.[11, 15, 16] Conditions that produced a significant IRR (>1, 95% confidence intervals to not intersect 1.0) were taken as “high risk conditions”. The analysis was then repeated for injury within 14, 21 and 28 days to determine the latent period.

Results

A total of 133 injuries were recorded over the course of the 4 seasons (33.3 ± 5.9/season) at an incidence of 11.7 injuries/1000 hours. Additional data pertaining to the average training loads attained in each season is provided in Supplementary Table A.

Table 1 presents the predictive accuracy of all variables. The AUC values ranged between 0.593 and 0.675, indicating “sufficient” diagnostic accuracy.[27] No significant difference was found between the AUCs for any variable, suggesting no timeframe was better than another for injury prediction. Therefore, the traditional 1:4 week ratio and 4 week chronic load were retained and used with each variable for further analysis.

>>>>>>>>>>>>>>>>>>>>>>>>>>INSERT TABLE 1 HERE<<<<<<<<<<<<<<<<<<<<<<<<<<<

The classifications of CTL categories are detailed in Table 2. Complete results can be found in Supplementary on-line material (Tables B to E). Most injuries occurred in the very low chronic load quartile, with 39%, 32% and 41% of injuries occurring in this category for distance, sprint distance and sRPE, respectively. High ACWRs also accounted for a significant number of injuries, with 3%, 10%, 18% and 8% occurring with ACWR >150%, for distance, sprint distance and sRPE, respectively. The majority of these high injury risk conditions carried an elevated risk for 21-28 days, as shown in Table 3.

>>>>>>>>>>>>>>>>>>>>>>>>>>INSERT TABLE 2 HERE<<<<<<<<<<<<<<<<<<<<<<<<<<<

>>>>>>>>>>>>>>>>>>>>>>>>>>INSERT TABLE 3 HERE<<<<<<<<<<<<<<<<<<<<<<<<<<<

The interaction between ACWR and CTL and the relationship with injury is demonstrated in the Supplementary on-line material (Figure 1). Second order polynomial (quadratic) curves were fitted for each variable following previously published processes.[16]

Discussion

To our knowledge, this is the first study to examine different timeframes for the ACWR in combination with chronic load in AF. Using other timeframe ratios did not improve the capacity to predict injury above the traditional 1:4 week ACWR analysis, thereby supporting the current use of this ratio. These findings contrast those by Carey et al.[18] who reported a 3-day:21-day and 6-day:21-day ACWR explained injury likelihood better than ratios derived from other timeframes. Unlike the present study, this report calculated ACWR daily instead of weekly. Further, ACWR was not considered in combination with chronic load despite the interaction effect previously demonstrated between these variables.[19] The present study also assessed the predictive value of the variables using a ROC curve, in contrast to selecting variables based on model fit diagnostics. The outcome of the current study supports the use of timeframes alternate to the traditional 1-week and 4-weeks if they are considered more practical in a given setting. A commonly cited limitation of the ACWR is that it cannot be calculated when data is unavailable during the chronic load period (e.g., start of pre-season, post-Christmas break). This study suggests injury risk can still be detected by lengthening or shortening the chronic loading period in these situations, without compromising the capacity of the model.

This study also demonstrates that injury risks identified by the ACWR are related to the chronic load from which they are derived. This has clinical importance, as this finding supports the position that the ACWR should not be examined in isolation when determining the risks associated with prescription of training loads.[15] Specifically, the highest injury risk occurred when chronic load was classified as low or very low. The notion of training load being protective against injury has been previously demonstrated and is the basis of the training load-injury paradox.[28] A 4 week workload of 5,000-8,500 AU was associated with the lowest injury risk when compared to low and high workloads in rugby union players,[11] and it was reported that high chronic GPS distance (18.9-22.0 km per week) reduced risk (compared to low values) when rugby league players had a short turnaround between matches[18]. Consistent with the quadratic relationship between ACWR and injury likelihood,[16] most of the high risk categories found were when ACWR was low (<0.6) or high (>1.5). These represent both a floor and a safety ceiling for relative loading parameters. These findings do not support complete avoidance of these ranges, but rather indicate scenarios where higher injury risk may be present. These risks should be contextualised to the individual's environment and associated factors which may protect against or increase injury risk, such as a high pre-season workload.[6]

A high chronic load combined with a moderate ACWR (1.02-1.18) has previously been shown as protective, compared to a number of ACWRs combined with a low chronic load.[15] Potentially, a moderate-high chronic load base allows players to tolerate greater load fluctuations than when chronic load is low. Interestingly, Hulin et al.[15] reported that in rugby league players a high ACWR (>1.54) combined with a high chronic workload (>16,095 m/week), resulted in the greatest injury risk (29%) of all ACWR and chronic load combinations. However, this is contradictory to our results. A potential explanation for this difference (see on-line supplementary material) is that in our study when chronic load was high or very high, ACWRs above 180% were rarely reached (particularly for distance and sRPE). During the AF in-season period, most of the weekly load is attained during the match. As such, when match load is consistent, variations in weekly training appear to produce limited fluctuations in total load. This potentially disguises the risk of high ACWR when chronic load is high. However, when a player has a low chronic load (e.g., returning from injury or subsequent to a bye-round), due to interrupted game continuity or low game loads, they are more likely to reach a high ACWR and be exposed to increased injury risk. A U-shaped relationship has previously been demonstrated between chronic load and injury, with high and low load conditions increasing injury likelihood compared to a moderate-high condition.[11] It is possible that ACWR becomes a greater risk factor in these low or very high chronic load conditions where risk is already elevated.

Although the influence of high ACWR on injury risk has been well documented,[13, 15] limited attention has been given to low ACWR. In the present study, several low ACWR risk conditions were identified. Given that ACWR was calculated weekly (on Mondays), it is likely that a low ACWR would result in a load spike later in the week, potentially accounting for the elevated risk. Therefore, a daily load analysis may be more appropriate for use by sports medicine/science staff in AF, which would also account for varied periods (i.e., number of days break) between games.

Of the high injury risk conditions identified, heightened risk persisted for 21-28 days for most cases, as indicated by the significant IRRs. To our knowledge, this is the first report of a latent period for injury risk in AF players, which supports research in fast bowlers reporting a 3-4 week risk elevation following high match workloads.[17] The increased risk for the subsequent month potentially explains reports of greater injury incidence early in the season (following pre-season games) in team sports.[29] It also highlights the need to conservatively manage players through this latency period to prevent injury realisation.

Although several significant results were found here, a limitation is acknowledged, as this study only involved players from a single AFL club. Furthermore, only in-season load and intrinsic injury data was included, as load data continuity was not available throughout the pre-season period (off-season and Christmas break). It is possible that risk factors would differ between pre-season and in-season, since the relationship between workload and injury has been shown to be modulated by the pre-season workload.[6] Only load from field training sessions was available, meaning weights and off-legs (e.g., swimming) conditioning sessions were excluded. The total workloads of the players were therefore higher than analysed. However, during the in-season phase, the weekly training loads from these modalities do not fluctuate greatly, as competition games are prioritised.[30] Other environmental factors such as sleep, nutrition and self-directed use of recovery strategies were also unable to be accounted for. Furthermore, previous injury history, which is known to a major injury risk factor,[3] was not considered here. It is recommended that future investigations include all training completed, examine load parameters on a daily (rather than weekly) basis and account for all known fixed risk factors. It is also acknowledged that the validity and reliability of GPS decreases with increased velocities. While, the variables examined in this study have demonstrated suitable reliability, sprint distance should be treated with greater caution than distance and sRPE. Lastly, staff at the AFL club were aware of the current literature, and as such, it is likely that the players were often managed away from increased injury risk conditions.

Conclusion

This investigation supports the use of training load monitoring in AF. The results demonstrate that higher chronic loads can protect against injury and supports the use of the 1:4 week ACWR, since no improvement is gained by manipulating the timeframes of the acute or chronic workload for either internal or external loads.

Practical Implications

- Best practice in team sports should include monitoring of ACWR, in conjunction with chronic loads, and using internal and external load measures.
- The ability to detect scenarios where increased injury risk is observed is not improved by altering the acute or chronic load timeframes beyond the commonly used 1:4 week ACWR.
- During the competition period in Australian football, maintaining a moderate to high workload is associated with lower injury incidence.
- When a player has a low chronic load, extreme ACWRs should be avoided to prevent entry into a "high injury risk condition" which is associated with an elevated risk for up to 28 days.
- Following a high injury risk condition, players should be managed conservatively for the subsequent month.

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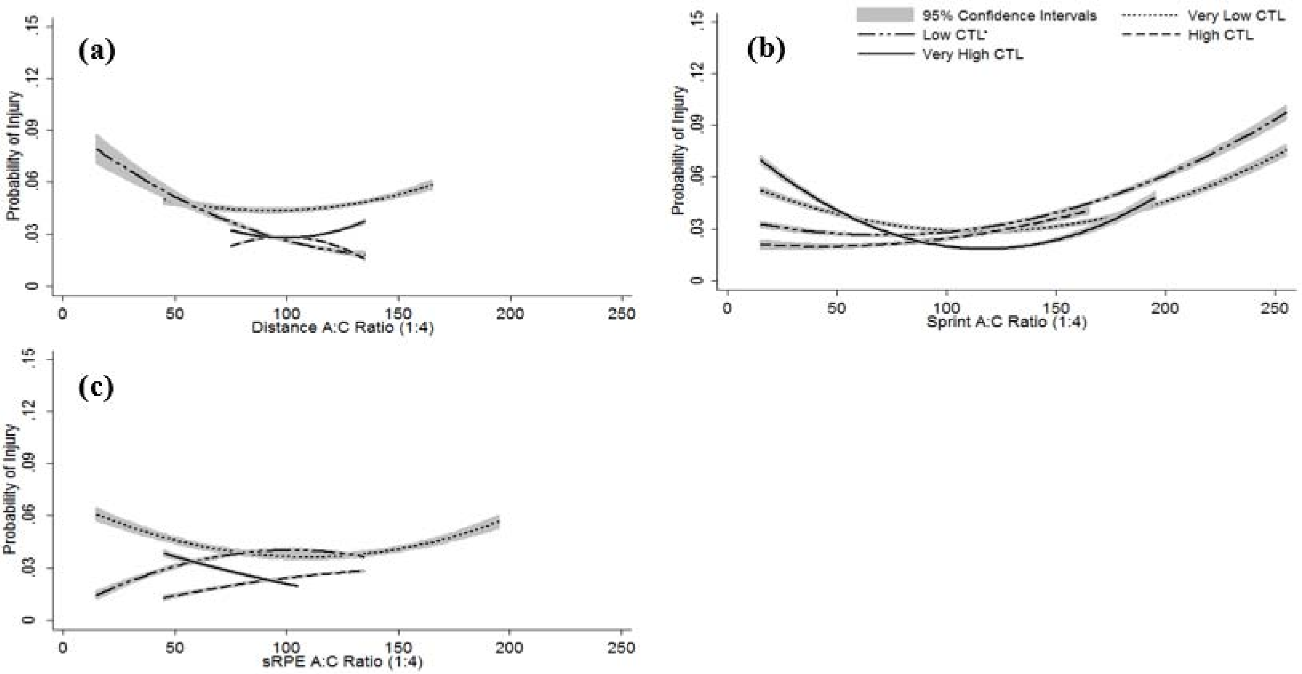
Figure 1 Fitted polynomial curves for probabilistic modelling of injury.



(a)
(b)
(c)
95% Confidence Intervals
Very Low CTL
Low CTL*
High CTL
Very High CTL
Probability of Injury
0
.03
.06
.09
.12
.15
0
50
100
150
200
250
Distance A:C Ratio (1:4)
Sprint A:C Ratio (1:4)
sRPE A:C Ratio (1:4)

Table 1 Comparison of the area under the curve (AUC) for various time frames for each of the three load variables in relation to injury within 7 days.

Variable	ACWR / CTL	AUC	Std Err	95% Confidence Intervals			*p-value*
Distance	1wk:3wk / 3week	0.600	0.027	0.54	-	0.65	0.759
	1wk:4wk / 4week	0.627	0.027	0.57	-	0.68	
	1wk:5wk / 5week	0.628	0.027	0.58	-	0.68	
	1wk:6wk / 6week	0.639	0.025	0.59	-	0.69	
	1wk:7wk / 7week	0.635	0.026	0.58	-	0.69	
	1wk:8wk / 8week	0.645	0.026	0.59	-	0.69	
	2wk:3wk / 3week	0.607	0.027	0.55	-	0.66	
	2wk:4wk / 4week	0.605	0.028	0.55	-	0.66	
	2wk:5wk / 5week	0.621	0.027	0.57	-	0.67	
	2wk:6wk / 6week	0.650	0.024	0.60	-	0.70	
	2wk:7wk / 7week	0.643	0.026	0.59	-	0.69	
	2wk:8wk / 8week	0.637	0.025	0.59	-	0.69	
Sprint Distance	1wk:3wk / 3week	0.649	0.024	0.60	-	0.70	0.317
	1wk:4wk / 4week	0.648	0.025	0.60	-	0.70	
	1wk:5wk / 5week	0.653	0.025	0.60	-	0.70	
	1wk:6wk / 6week	0.645	0.025	0.60	-	0.69	
	1wk:7wk / 7week	0.669	0.025	0.62	-	0.72	
	1wk:8wk / 8week	0.646	0.025	0.60	-	0.69	
	2wk:3wk / 3week	0.593	0.027	0.54	-	0.65	
	2wk:4wk / 4week	0.622	0.026	0.57	-	0.67	
	2wk:5wk / 5week	0.617	0.026	0.57	-	0.67	
	2wk:6wk / 6week	0.631	0.026	0.58	-	0.68	
	2wk:7wk / 7week	0.600	0.026	0.55	-	0.65	
	2wk:8wk / 8week	0.636	0.025	0.59	-	0.69	
On-legs sRPE	1wk:3wk / 3week	0.632	0.026	0.58	-	0.68	0.504
	1wk:4wk / 4week	0.624	0.027	0.57	-	0.67	
	1wk:5wk / 5week	0.607	0.027	0.55	-	0.66	
	1wk:6wk / 6week	0.627	0.026	0.58	-	0.68	
	1wk:7wk / 7week	0.651	0.025	0.60	-	0.7	
	1wk:8wk / 8week	0.645	0.025	0.60	-	0.7	
	2wk:3wk / 3week	0.641	0.025	0.59	-	0.69	
	2wk:4wk / 4week	0.639	0.026	0.59	-	0.69	
	2wk:5wk / 5week	0.642	0.026	0.59	-	0.69	
	2wk:6wk / 6week	0.648	0.025	0.60	-	0.70	
	2wk:7wk / 7week	0.665	0.025	0.62	-	0.71	
	2wk:8wk / 8week	0.675	0.024	0.63	-	0.72	

ACWR = Acute:chronic workload ratio (1 week:4 week); CTL = Chronic Training Load (weekly average over past 4 weeks); sRPE =Sessional Rating of Perceived Exertion; *P*-value = statistical significance (difference between any 2 variables analysed).

Table 2 Classifications of 4-week Chronic load for each variable

Variable	Very Low	Low	High	Very High
Distance (m)	<18834	18834-20892	20892-22762	>22762
Sprint Distance (m)	<190	190-272	272-368	>368
On-legs sRPE (AU)	<982	982-1144	1144-1306	>1306

sRPE = On-legs Sessional Rating of Perceived Exertion.

Table 3 Incident Rate Ratios (IRR) for injury in the 7, 14, 21 and 28 days subsequent to entering a high injury risk condition.

High Risk Condition				Relative Risk							
Chronic Load Category	Chronic Load Variable	ACWR Variable	ACWR Range (%)	7 days		14 days		21 days		28 days	
				IRR	*p*	IRR	*p*	IRR	*p*	IRR	*p*
Very Low	Distance	sRPE	1.8-2.1	4.96*	0.00	5.67*	0.00	6.93*	0.00	4.89*	0.00
	Sprint Distance	Distance	1.5-1.8	3.31*	0.02	3.00*	0.02	2.53*	0.02	2.36	0.07
		Sprint Distance	2.1-3.0	3.04*	0.03	2.36*	0.02	1.94*	0.03	1.47	0.20
		sRPE	1.8-2.1	6.36*	0.00	4.58*	0.00	3.51*	0.01	2.81*	0.03
	sRPE	Sprint Distance	2.1-3.0	3.14*	0.03	2.11*	0.04	2.39*	0.01	1.78	0.07
		Sprint Distance	0.0-0.3	2.84*	0.02	1.56	0.19	2.06*	0.02	1.61	0.07
		sRPE	1.8-2.1	3.21*	0.01	3.32*	0.00	3.47*	0.00	2.71*	0.00
		sRPE	0.3-0.6	2.25*	0.03	2.38*	0.02	2.18*	0.02	2.15*	0.01
Low	Distance	Distance	0.0-0.3	8.19*	0.02	5.49	0.06	4.16	0.11	3.16	0.19
		Sprint Distance	1.8-2.1	3.74*	0.02	2.63*	0.04	2.46	0.05	1.69	0.24
		Sprint Distance	2.1-3.0	3.71*	0.03	3.91*	0.00	3.83*	0.00	2.86*	0.01
	Sprint Distance	Sprint Distance	2.1-3.0	5.11*	0.02	3.37*	0.01	3.21*	0.00	2.41*	0.03

Risk is measured by incidence rate ratios with the reference category of: ACWR = 0.9-1.2, Chronic Load: High; * significant increase in risk compared to the reference category;
ACWR= acute to chronic workload ratio (1:4 weeks), IRR= incidence rate ratios, *p*= p-value: statistical significance, RVC= relative velocity change.