

# Workload is Associated with the Occurrence of Non-Contact Injuries in Professional Male Soccer Players: A Pilot Study

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## Research Article

**Keywords:** ACWR, external load, football, prevention, performance, injury risk

**Posted Date:** April 9th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-390515/v1>

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# Abstract

**Background:** Injuries in professional soccer are a significant concern for teams, and they are, mostly, caused by high training load. This cohort study described the relationship between workload parameters with the occurrence of non-contact injuries, during weeks with high and low workload in professional soccer players throughout the season.

**Methods:** Twenty-one professional soccer players aged  $28.3 \pm 3.9$  yrs. who competed in the Iranian Persian Gulf Pro League participated in this 48-week study. The external load was monitored using global positioning system (GPS, GPSPORTS Systems Pty Ltd) and the type of injury was documented by the team's medical staff daily. Odds ratio (OR) and relative risk (RR) were calculated for non-contact injuries for high- and low-load weeks according to acute (AW), chronic (CW), acute to chronic workload ratio (ACWR), and AW variation ( $\Delta$ -Acute) values. By using Poisson distribution, the interval between previous and new injuries were estimated.

**Results:** Overall, 12 non-contact injuries occurred during high load and 9 during low load weeks. Based on the variables ACWR and  $\Delta$ -AW, there was a significantly increased risk of sustaining non-contact injuries ( $p < 0.05$ ) during high-load weeks for ACWR (OR: 4.67), and  $\Delta$ -AW (OR: 4.07). Finally, the expected time between injuries was significantly shorter in high load weeks for ACWR [1.25 vs 3.33, rate ratio time (RRT)] and  $\Delta$ -AW [1.33 vs 3.45, RRT] respectively, compared to low load weeks.

**Conclusion:** The risk of sustaining injuries was significantly larger during high workload weeks for ACWR, and  $\Delta$ -AW compared with low workload weeks. The high numbers for OR in high load weeks indicate that there is a significant relationship between workload and occurrence of non-contact injuries. The predicted time to new injuries is shorter in high load weeks compared to low load weeks. Therefore, the frequency of injuries is higher during high load weeks for ACWR and  $\Delta$ -AW. ACWR and  $\Delta$ -AW appear to be good indicators for estimating the injury risk, and the time interval between injuries.

## Introduction

Soccer is a high-intensity intermittent team sport that involves vigorously high and low exercises, and requires a significant level of endurance [1]. Mean injury incidence, considering matches and training sessions across seven UEFA clubs during seven seasons, was reported as 50 injuries per season in a team (N = 25) which equals two injuries per player and season [2]. Non-contact injuries like anterior cruciate ligament injuries, occurred most often due to the sudden deceleration and repeatedly performed pivoting maneuvers [3]. Therefore, injuries in professional soccer are a significant concern for teams, and injury prevention in elite soccer should be considered important. Most injuries are caused by high training load, in the meantime, external training load, which consists of various training variables such as body load (BL), acceleration, speed, metabolic power, etc. can be used as a monitoring tool to prevent injuries [4]. Therefore, different workload parameters obtained from training load have been used to detect injury risk in different activities [5].

Training load is usually classified into measures of external and internal load. External load refers to all movements of the players, and can be assessed by some micro electromechanical devices such as global

positioning systems (GPS), local positioning systems, and inertial measurement units [6]; while internal load refers to the athletes' biological responses to an external load, such as heart rate and ratings of perceived exertion [7]. GPS is the most used tracking tool to collect external workloads during training in team sports [8], and it has been shown that GPS is a valid and reliable tool to monitor training [9]. Some studies on the workload and related injuries among professional soccer players have confirmed the importance of monitoring the workload of players to prevent injury [10, 11]. Typically, acute (AW), chronic (CW), and AW/CW workload ratio (ACWR) are good indicators to reflect the relationship between fatigue (related to AW) and fitness (related to CW) of the players, which have been associated with non-contact injury [12, 13]. Players with a high CW were more resistant to injury compared to players who had a low CW [14]. Overall, when the ACWR is within the range of 0.8–1.3 arbitrary unit (A.U.), the injury probability is low ("sweet spot"), and when this ratio exceeds 1.5 A.U., the injury probability doubles [15]. Malone et al. [16] reported that there is an association between high ACWR > 2.0 A.U. and increased probability of injury within team sport athletes. In cricket, using ACWR, it has been demonstrated that higher CW protect against injury [17]. Impellizzeri et al. [18] concluded that no evidence suggests the use of ACWR in managing training loads to reduce injury risk. However, Gabbett [6] stated that excessive and rapid increases in training loads are probably responsible for most non-contact injuries. In 2016, the International Olympic Committee published a consensus statement which suggests the use of the ACWR approach for injury prevention [19]. Therefore, monitoring players' workload may help to reduce the risk of sustaining injuries, time off from competitions, and the costs related with injuries.

Considering the importance of workload monitoring to prevent non-contact injuries in elite soccer players, this study aimed to examine the role of the incidence rate for non-contact injuries, during high vs. low load weeks across a full soccer season using odds ratio (OR) and relative risk (RR). Also, an investigation into the relationship between AW, CW, ACWR, and AW variation ( $\Delta$ -Acute) with non-contact injury incidence rate in professional players throughout a full soccer season and ultimately, the estimation of the predicted time between old injuries to new injury using Poisson distribution. We hypothesized that high training load per week will be associated with higher non-contact injury OR and RR [16].

## **Material And Methods**

### **Participants**

Twenty-one professional soccer players aged  $28.3 \pm 3.9$  yrs from the Iranian Persian Gulf Pro League volunteered to participate in this study for a full season. Goalkeepers were excluded from study participation. The athletic/fitness coaches of the club, after obtaining permission from the relevant authorities and the head coach of the club, designed and programmed the soccer training. Before commencing the study, it also received the approval of the research ethics committee from the University of Isfahan (IR.UI.REC.1399.064). All players were informed of the purpose of the study before completing the informed consent. All stages of this study were carried out based on the ethical principles in the Helsinki Declaration.

### **Study design**

The study was performed longitudinally in a full season for 48 weeks in the Persian Gulf Pro League and knockout tournament. GPS (GPSPORTS systems Pty Ltd, Model: SPI High-Performance Unit (HPU), Canberra, Australia) was used for monitoring the external load at each training and match sessions during the whole season. All non-contact injuries were recorded during the season. During the whole season, 7-weeks congested (i.e., two or more matches within 7-days), 30-weeks non-congested; 44 matches, 200 training sessions, and 14126.8 minutes of time played and sessions were held. All workload parameters including AW, CW, ACWR, and  $\Delta$ -Acute were calculated. Afterwards, each variable was divided into two levels, high and low, and subsequently, the relationship between the variables was measured.

## Procedures

### *External load*

*GPS receiver specifications.* GPSPORTS systems Pty Ltd, recorded all players' activities in training sessions and matches. The GPS-based tracking systems for professional athletes, model SPI HPU features included: 15 Hz position GPS, distance, and speed measurement; accelerometer: 100 Hz, 16 G Tri-Axial-Track impacts, accelerations, and decelerations as well as data source BL; Mag: 50 Hz, Tri-Axial; dimensions: 74 mm × 42 mm × 16 mm; SPI HPU based on Mining/Industrial Strength Electronics design; water resistance and data transmission: infra-red and weighs 56 g. Previous studies have shown that the GPS unit was tested for having a very high accuracy, demonstrated validity and inter-unit reliability, also, the intraclass correlation coefficients were high (>0.95) [20]. Data collecting during training sessions and matches was performed in favorable weather and GPS satellite status.

*Data collection.* Data collection was completed as in previous studies [21, 22]. At pre-session, we placed upright tracking units in the pouch of the manufacturer supplied belt, then the green light (GPS tracking) flashes were checked. At post-session, after verifying each unit was working properly, tracking units that collected the players' data were placed on the docking station. After 10 minutes, units turned off automatically, and data that were downloaded into docking memory were deleted from the units to prepare for the next session. The GPS units were tuned to the default SPI IQ Absolutes in this study. Duration in minutes and BL was calculated by accelerometer data, and it is designed to reflect both volume and intensity events of the accelerometer (acceleration). BL had replaced the original GPSports BL variable; it is an integrated loading variable used as a training load marker (BL) and work rate marker (BL/min), which we applied as a criterion for the training load in the current study. As to BL calculation, the following steps were repeated for each acceleration level: initialize the BL count to 0; magnitude of the acceleration vector (V) was calculated for the current acceleration ( $V = \sqrt{a_x^2 + a_y^2 + a_z^2}$ ); normalize the magnitude vector (NV) by subtracting a national 1G ( $NV = V - 1.0 \text{ G}$ ); afterwards unscaled BL (USBL) was calculated through the formula  $USBL = NV + [NV^3]$ ; then, the scaled BL (SBLC) was calculated taking into account the accelerometer logging rate (100 HZ) and exercise factor (EF) ( $SBLC = USBL/100/EF$ ); ultimately, final BL was calculated ( $BL = BL + SBLC$ ).

## Calculation of workload parameters

*Workload calculated.* In this study, BL was used as the criterion for the training workload [21, 22]. Weekly training workload was used to calculate other workload parameters.

*Acute workload (AW) calculation.* We recorded the mean weekly AW of the team over the 48 weeks of the season.

*Chronic workload (CW) calculation.* We recorded the average weekly CW of the team between weeks 4 and 48 (45 weeks). The CW of each player was calculated with the following formula [23, 24]: where n = week number

$$CW = (AW_{n-1} + AW_{n-2} + AW_{n-3}) \times 0.333$$

*ACWR calculation.* The mean ratio between the AW and CW of the team was calculated and recorded with this variable. The ratio between the individual AW and CW was calculated with the following formula [23, 25]: where n = week number

$$ACWR = \frac{AW_n}{(AW_{n-1} + AW_{n-2} + AW_{n-3}) \times 0.333}$$

*$\Delta$ -Acute load calculation.* The AW variation between weeks was calculated through the formula: where n = week number

$$\Delta\text{-Acute} = \frac{AW_n}{CW_n}$$

*AW level division.* Difference between "high load" and "low load" weeks according to the average weekly AW of the team. "high load" was defined as  $AW \geq 571$  and "low load" was defined as  $AW < 571$ . The cut-off point was established as follows: all the weeks of the season were ordered from highest to lowest AW load, the upper 1.3 was taken as high load and the lower 2.3 as low load.

*CW level division.* The difference between "high load" and "low load" weeks according to the average weekly CW of the team was calculated. "high load" was defined as  $CW \geq 541$  and "low load" was defined as  $CW < 541$ . The cut-off point was established as follows: all the weeks of the season, with values of CW (45 last weeks) were ordered from highest to lowest CW load, the upper 1.3 was taken as high load and the lower 2.3 as low load.

*ACWR level division.* The difference between "high load" and "low load" weeks according to the average weekly ACWR of the team was calculated. "high load" was defined as  $ACWR \geq 1.18$  and "low load" was defined as  $ACWR < 1.18$ . The cut-off point was established as follows: all the weeks of the season, with values of ACWR were ordered from highest to lowest ACWR load, the upper 1.3 was taken as high load and the lower 2.3 as low load.

*$\Delta$ -Acute level division.* The difference between "high load" and "low load" weeks according to the average weekly  $\Delta$ -Acute of the team. "high load" was defined as  $\Delta\text{-Acute} \geq 1.19$  and "low load" was defined as  $\Delta\text{-Acute} < 1.19$ .

Acute < 1.19. The cut-off point was established as follows: all the weeks of the season, with values of  $\Delta$ -Acute, were ordered from highest to lowest  $\Delta$ -Acute load, the upper 1.3 was taken as high load and the lower 2.3 as low load.

### **Recording and calculating injury**

Information on injuries was updated daily by the team's specialized medical staff. Based on a previous study, all injuries were recorded by type, location of the injury, and timing of the injury [26]. The information used for the injuries is as follows:

*The number of registered injuries.* The total number of non-contact injuries per week for the team, over the 48 weeks of the season, was recorded with this variable.

*Weekly injury.* The existence or not of a non-contact injury in each of the 48 weeks of the season was recorded.

### **Statistical analyses**

The statistical software IBM Statistics 25 and R Studio 3.6.2. were used for statistical analyses. Accordingly, data were presented as means and standard deviations. A descriptive statistical analysis was realized, indicating the median values and interquartile range of the levels "high load" and "low load" for the variables "AW", "CW", "ACWR" and " $\Delta$ -AW," as well as the total values. Non-parametric Mann-Whitney U tests were realized to compare the median of the load levels of the previous variables, checking the existence of statistically significant differences between them. A normality test, Kolmogorov-Smirnov, was performed, determining that the variables "number of injuries" and level of "AW", "CW", "ACWR" and " $\Delta$ -AW" did not follow a normal distribution. Additionally, a descriptive analysis of the number of injuries produced in the weeks of high and low load of each one of the variables was completed, as well as the calculation of the median of each one of them, both for the two levels of load as well as for the total. In the purpose of detecting statistically significant inter-group differences between the median of injuries of the "high load" and "low load" levels of the variables "high load" and "low load" for the variables "AW", "CW", "ACWR" and " $\Delta$ -AW", non-parametric tests were carried out, taking into account, as factors, the load levels of each variable. A contrast of proportions was made to check the existence of significant differences between the levels of "high load" and "low load" of each variable and the weeks with the injury. To estimate the injury risk associated with high or low load level, the OR and RR were calculated. Finally, the variable "number of injuries" followed a Poisson distribution, so the Poisson test was performed to obtain lambda values (average number of injuries per week for each level of load), and the expected time until a new injury occurs. For checking possible significant differences between load levels, in addition to calculating the rate ratio, their confidence intervals 95% (CI 95%) were stated.

## **Results**

Overall, 12 non-contact injuries occurred during high load and 9 during low load weeks. The analysis revealed significant differences between "high" and "low" load levels for the AW, CW, ACWR, and  $\Delta$ -AW variables (Table 1).

Table 1  
Descriptive information of workload parameters based on high and low level load

Workload variables	High load	Low load	<i>P</i>	Total
	Median (IQR)	Median (IQR)		Median (IQR)
AW (A.U.)	650 (608–732)	453 (395–492)	< 0.001***	491 (409–611)
CW (A.U.)	577 (567–638)	473 (447–504)	< 0.001***	501 (462–567)
ACWR (ratio)	1.30 (1.23–1.50)	0.91 (0.79–1.04)	< 0.001***	1.06 (0.88–1.21)
Δ-AW (ratio)	1.35 (1.30–1.60)	0.83 (0.67–0.99)	< 0.001***	0.99 (0.75–1.30)

IQR: Interquartile range; A.U.: Arbitrary units; Acute workload (AW): High load (Weeks with loads  $\geq 571$  A.U.) and low load (Weeks with loads  $< 571$ ); Chronic workload (CW): High load (weeks with loads  $\geq 541$ ) and low load (weeks with loads  $< 541$ ); Acute chronic workload ratio (ACWR): High load (weeks with loads  $\geq 1.18$ ) and low load (weeks with loads  $< 1.18$ ); Increment in acute workload ( $\Delta$ -AW): High load ( $\Delta$ -AW  $\geq 1.19$ ) and low load ( $\Delta$ -AW  $< 1.19$ ); *p* (*p*-value); \*\*\*(*p* < 0.001).

It was appreciated that a superior mean of injuries occurred in the weeks of high load, in comparison to the weeks of low load for ACWR and  $\Delta$ -AW, but no differences were observed in the variables AW and CW (Table 2).

Table 2  
The relation between AW, CW, ACWR, and  $\Delta$ -AW with non-contact injuries.

Workload variables	High load			Low load			<i>p</i>	Total		
	Injuries	Weeks	M	Injuries	Weeks	M		Injuries	Weeks	M
AW (A.U.)	10	16	0.63	11	32	0.34	0.193	21	48	0.44
CW (A.U.)	8	15	0.53	13	30	0.43	0.413	21	45	0.47
ACWR (ratio)	12	15	0.80	9	30	0.30	0.011**	21	45	0.47
Δ-AW (ratio)	12	16	0.75	9	31	0.29	< 0.001*	21	47	0.45

Mean (M); Arbitrary units (A.U.); Acute workload (AW): High load (Weeks with loads  $\geq 571$  A.U.) and low load (Weeks with loads  $< 571$ ); Chronic workload (CW): High load (weeks with loads  $\geq 541$ ) and low load (weeks with loads  $< 541$ ); Acute chronic workload ratio (ACWR): High load (weeks with loads  $\geq 1.18$ ) and low load (weeks with loads  $< 1.18$ ); Increment in acute workload ( $\Delta$ -AW): High load ( $\Delta$ -AW  $\geq 1.19$ ) and low load ( $\Delta$ -AW  $< 1.19$ ); *p* (*p*-value); \*\*\*(*p* < 0.001); \*\*(*p* < 0.05) and \*(*p* < 0.05).

The contrast of proportions between the high and low load levels of each of the variables, and the number of weeks with and without injuries were calculated. Results indicated no significant differences between the proportions of weeks with and without injuries for the high and low load levels of the variables AC and CW. There were significant differences (*p* < 0.05) in the proportion of weeks without injuries between the high and low load weeks of the variables ACWR and  $\Delta$ -AW.

In the four variables of interest, during the weeks with high load levels, the OR of producing non-contact injuries were significantly higher for ACWR and  $\Delta$ -AW in comparison with the weeks of low load. While in the RR, the significant differences were not found for all variables. (Table 3).

Table 3  
Injury risk related to different load levels and workload parameters with OR and RR.

Workload variables	High load		Low load		OR	CI95%		RR	CI95%	
	INJURY	TOTAL	INJURY	TOTAL		MIN	MAX		MIN	MAX
	(No injury)		(No injury)							
AW (A.U.)	8 (8)	16	11 (21)	32	1.91	0.56	6.48	1.31	0.76	2.28
CW (A.U.)	8 (7)	15	11 (19)	30	1.97	0.56	6.94	1.36	0.74	2.50
ACWR (ratio)	10 (5)	15	9 (21)	30	4.67	1.24	17.60	2.10	0.99	4.46
$\Delta$ -AW (ratio)	10 (6)	16	9 (22)	31	4.07	1.14	14.58	1.89	0.97	3.70

Arbitrary units (A.U.); Acute workload (AW): High load (Weeks with loads  $\geq$  571 A.U.) and low load (Weeks with loads  $<$  571); Chronic workload (CW): High load (weeks with loads  $\geq$  541) and low load (weeks with loads  $<$  541); Acute chronic workload ratio (ACWR): High load (weeks with loads  $\geq$  1.18) and low load (weeks with loads  $<$  1.18); Increment in acute workload ( $\Delta$ -AW): High load ( $\Delta$ -AW  $\geq$  1.19) and low load ( $\Delta$ -AW  $<$  1.19); Injury (weeks with injuries). No injury (weeks without injuries).; Total (total weeks); OR (Odds Ratios); RR (Relative risk); CI95% (confidence interval); Min (Minimum); Max (Maximum).

Finally, it was observed that the time between injuries was shorter during weeks of high load compared to weeks of low load. However, only significant differences were found in the variables ACWR and  $\Delta$ -AW between weeks of high and low load (Table 4).

Table 4  
Relationship between injuries and different levels of load to find the expected time until new injuries.

Workload variables	High load		Low load		<i>p</i>	Rate ratio	CI95%	
	$\lambda$	Expected time injury	$\lambda$	Expected time injury			MIN	MAX
	AW (A.U.)	0.63	1.6	0.34			2.94	0.17
CW (A.U.)	0.53	1.9	0.43	2.32	0.64	1.23	0.44	3.20
ACWR (ratio)	0.80	1.25	0.30	3.33	0.034*	2.66	1.03	7.17
$\Delta$ -AW (ratio)	0.75	1.33	0.29	3.45	0.036*	2.59	1.00	6.94

Arbitrary units (A.U.); Acute workload (AW): High load (Weeks with loads  $\geq$  571 A.U.) and low load (Weeks with loads  $<$  571); Chronic workload (CW): High load (weeks with loads  $\geq$  541) and low load (weeks with loads  $<$  541); Acute chronic workload ratio (ACWR): High load (weeks with loads  $\geq$  1.18) and low load (weeks with loads  $<$  1.18); Increment in acute workload ( $\Delta$ -AW): High load ( $\Delta$ -AW  $\geq$  1.19) and low load ( $\Delta$ -AW  $<$  1.19);

Expected time injury (Expected time between injuries.  $1/\lambda$ );  $p$  ( $p$ -value); \* $p < 0.05$ ; CI95% (Confidence interval); MIN (minimum); MAX (maximum); Rate ratio (Expected time injury low load/Expected time injury high load).

## Discussion

The purpose of this study was to investigate the association of workload with the OR and RR of non-contact injuries in male professional soccer players. In the present study, external load monitoring was performed by GPS at each training and match sessions during the whole season. In this study, the number of recorded non-contact injuries across the soccer season amounted to 21, and it is similar in magnitude to that reported in a previous study [2]. Also, according to Arazi et al., 21 subjects would be suitable for a relationship between workload parameters and injury rate with reduced chances of a Type II error [27]. In the soccer players AW, CW, ACWR, and  $\Delta$ -Acute workload parameters were calculated, while each variable was divided into two levels, "high-load" or "low-load" level. According to the results, there were significant differences in the proportion of weeks with injury between high load and low load weeks. The OR of producing injuries without contact were significantly higher for ACWR and  $\Delta$ -AW in comparison with the weeks of low load. Also, it was observed that the expected time between injuries was shorter between high load weeks rather than low load weeks.

The relationship between the AW, CW, ACWR, and  $\Delta$ -Acute with non-contact injuries in professional players was investigated. Statistically significant differences between "high" and "low" load levels were observed in all variables (AW, CW, ACWR, and  $\Delta$ -Acute), and the mean of injuries for AW, ACWR, and  $\Delta$ -AW variables was higher in the high load weeks in comparison to the low load weeks. In this regard, some workload-injury investigations showed similar relationships between absolute workloads and incidence of injury [28, 29]. Also, a study in elite rugby players showed that the ones who had very high ACWR, as well as high CW, had the largest risk of injury [30], while another study stated that higher CW protects against injury [31]. Using ACWR provides a better understanding of the relationship between workload and injury risk in sports like soccer [32], rugby [30], and cricket [33]. Gabbett et al. stated that the reason for using ACWR is that higher acute load compared to chronic load illustrates athlete unpreparedness, thus increasing injury risk [34], while Impellizzeri et al. concluded that no evidence shows the use of ACWR in managing training load to reduce injury risk [18]. Likewise, another study mentioned that using ACWR as an explanatory variable provides results which are always influenced by artifacts and artificial alterations. It means any errors like reducing the variance of the explanatory variable, representation of any information, unjustified reclassifications, equipment, technique, and so on. Considering that ACWR is a ratio and it is affected by its denominator, the players with low AW tend to have higher ACWR [35]. However, according to Malone et al., ACWR values between 1.00 and 1.25 A.U. were associated with lower injury incidence in professional soccer players [10], while ACWR values between 0.85 and 1.35 A.U. reduced the injury risk in rugby league groups [14]. The estimation of injury risk associated with high load level compared to low load level was considered. In our study, the ACWRs were 1.30 (CI 95%= 1.23–1.50 A.U.) during high load level and 0.91 (CI 95%=0.79–1.04 A.U.) during low load level. Considering the previous findings, RR increased while participants were in high load levels while RR was reduced in low load levels.

High AW [10], cumulated weekly [36, 37], and week to week changes [37] have been related to increased injury risk. Colby et al. reported that there is a positive linear relationship between cumulative loads and injury risk

[38], which is in agreement with our results. In our study, the mean of CW deviated from 0.53 to 0.43 in high load level to low load level, with a higher proportion of injuries in weeks of high load compared to weeks of low load, although there were no significant differences.

The OR describes the ratio of injury/disease odds given exposure status, although it is used especially in rare disease assumptions [39]. Therefore, if the rare disease assumption does not hold, it may be better to report RR. An OR and RR that are  $> 1.00$  means that the risk is increased, which in the current study, OR and RR were  $> 1.00$  for all variables. The OR and RR that are related to ACWR dedicated the largest number, 4.67 and 2.10, respectively, which determine that ACWR can better predict the risk of non-contact injuries. The current findings completely align with the Hulin et al. study that found GPS tracked ACWR predicted injury in elite rugby league players [30].

The relationship between injuries and different levels of load needed to find the expected time to new injuries was examined. In the current study, a Poisson test was done which provided two results. Firstly, the predicted time between injuries to new injury and secondly, lambda values. Lambda values ( $\lambda$ ) indicate the average number of injuries per week related to both high load and low load levels. Regarding this value and ACWR, in high load level (weeks with loads  $\geq 1.18$  A.U.) the average number of injuries per week was 0.80, which was the largest number among all variables. The expected time between injuries which, interestingly, has an inverse relationship with  $\lambda$  was 1.33 for the  $\Delta$ -AW variable, and 1.25 for the ACWR variable. Therefore, the predicted time between current injuries to new injuries is short and new injuries happen frequently.

This study has some limitations. First, OR and RR are the same in rare events [40], which means that by considering non-contact injuries in elite soccer players is not a rare event, it is more suitable to only report RR. The RR has been reported by its CI 95%, and it has been suggested that RR and CI 95% are presented for research investigating sports injuries [41]. Second, the sample size in this study, although similar to previous studies [42, 43], was small. It is recommended that to be able to generalize the findings of this study to a broader population, the sample size should increase. Also, integrating both internal and external loads as metrics for injury risk should be considered in future studies [44]. However, the strength of the present article is its specificity for male elite soccer players and highly accurate GPS units.

## Conclusions

In conclusion, in high load weeks compared to low load weeks, the number of injuries for AW, ACWR,  $\Delta$ -AW variables was increased. Also, by considering ACWR, the injury risk during high load levels was augmented. The predicted time to new injury decreased in high load weeks, therefore, the frequency of injuries increased. Our findings suggest ACWR is an acceptable indicator for estimating injury risk and the time interval between injuries in soccer.

This study has practical applications for the monitoring of injury risk during high load weeks in professional soccer. It is recommended that coaches and practitioners regularly monitor the training load, ACWR, and AW applied to athletes. This monitoring may allow increased time between injuries, thus delaying new injury in professional soccer.

# Abbreviations

OR: odds ratio; RR: relative risk; AW: acute workload; CW: chronic workload; ACWR: acute to chronic workload ratio;  $\Delta$ -Acute: AW variation; BL: body load; GPS: global positioning system; A.U.: arbitrary units; CI 95%: confidence interval. USBL: unscaled BL.

# Declarations

## Ethics Approval and Consent to Participate

The training coaches of the club, after obtaining permission from the relevant authorities and the head coach of the club, conducted this research. Before commencing the study, it also received the approval of the research ethics committee from the University of Isfahan (IR.UI.REC.1399.064). All players were informed of the purpose of the study before completing the informed consent. All stages of this study were carried out based on the ethical principles in the Helsinki Declaration.

## Consent for Publication

Not applicable

## Availability of data and materials

The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

## Competing interests

The authors declare that they have no competing interests.

## Funding

This research received no external funding.

## Author's contributions

Conceptualization, H.N., S.M.K., A.D.Z., and T.G.B., methodology, H.N., A.D.Z., U.G. and T.G.B., data collection, H.N., analysis, H.N., A.D.Z., U.G. and J.C.A, writing—original draft preparation, H.N., S.M.K., and A.D.Z., writing—review and editing, H.N., S.M.K., U.G., J.P.G., A.D.Z. and T.G.B. All authors have read and agreed to the published version of the manuscript.

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