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Section: Original Investigation

Article Title: Aerobic Fitness and Playing Experience Protect Against Spikes in Workload: The Role of the Acute:Chronic Workload Ratio on Injury Risk in Elite Gaelic Football

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Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: June 20, 2016

DOI: http://dx.doi.org/10.1123/ijspp.2016-0090

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Preferred Running Head: Load and injury in Gaelic football.

Abstract Word Count: 250

Text-Only Word count: 3000

Number of Tables: 6

Number of Figures: 0

ABSTRACT

Purpose: To examine the association between combined session-RPE workload measures and injury risk in elite Gaelic footballers. **Methods:** Thirty-seven elite Gaelic footballers (mean ± SD age of 24.2 ± 2.9 yr) from one elite squad were involved in a single season study. Weekly workload (session-RPE multiplied by duration) and all time-loss injuries (including subsequent week injuries) were recorded during the period. Rolling weekly sums and week-to-week changes in workload were measured, allowing for the calculation of the 'acute:chronic workload ratio' that was calculated by dividing acute workload (i.e. 1-week workload) by chronic workload (i.e. rolling average 4-weekly workload). Workload measures were then modelled against all injury data sustained using a logistic regression model. Odds ratios (OR) were reported against a reference group. **Results:** High 1-weekly workloads (≥2770 AU, OR = 1.63 – 6.75) were associated with significantly higher risk of injury compared to a low training load reference group (<1250 AU). When exposed to spikes in workload (acute:chronic workload ratio >1.5), players with 1 year experience had a higher risk of injury (OR = 2.22) and players with 2-3 (OR = 0.20) and 4-6 years (OR = 0.24) of experience had a lower risk of injury. Players with poorer aerobic fitness (estimated from a 1 km time trial) had a higher injury risk compared to players with higher aerobic fitness (OR = 1.50-2.50). An acute:chronic workload ratio of (≥2.0) demonstrated the greatest risk of injury. **Conclusions:** These findings highlight an increased risk of injury for elite Gaelic football players with high (>2.0) acute:chronic workload ratios and high weekly workloads. A high aerobic capacity and playing experience appears to offer injury protection against rapid changes in workload and high acute:chronic workload ratios. Moderate workloads, coupled with moderate-high changes in the acute:chronic workload ratio appear to be protective for Gaelic football players.

INTRODUCTION

Gaelic Football is a field sport with a similar structure to Australian football. Best described as a team based running game, it requires a combination of athleticism with skilful hand and foot passing [1, 2]. Gaelic Footballers are amateur athletes who train up to five times per week across strength, conditioning and technical pitch based sessions [2]. However the process of applying appropriate workloads in a constantly evolving environment is difficult for coaches [3]. Adequate workloads are required to improve athletic performance; however there is also a relationship between workloads, player fatigue and injury risk [4]. Injury events impact individual and team performance [5, 6]. Given this impact, the prescription of appropriate training loads requires careful consideration in order to maximise the positive and minimise negative effects of training. [6]

Gabbett and Domrow [7] analysed training loads and injury risk through regression analysis within 183 sub-elite Rugby League players, finding increased risk of injury in the pre-season (OR = 2.12), early in-season (OR = 2.85) and late in-season (OR = 1.50) phases for each arbitrary unit increase in training load. Within Australian Football, Rogalski et al. [8] reported that larger 1-weekly (>1750 arbitrary units, OR= 2.44–3.38), 2-weekly (>4000 arbitrary units, OR= 4.74) were associated with increased injury risk. Furthermore, previous to current week changes in load of 75% (>1250 arbitrary units, OR = 2.58) were also significantly related to greater injury risk throughout the in-season phase when compared to the reference group of 15% (250 arbitrary units). Additionally, when the previous to current week change in load was more than 1000 arbitrary units, players with less experience had a significantly lower injury risk than players with more experience (OR = 0.22-0.28). More recently, the association between in-season training load and risk of lower limb injury has been analysed in Rugby Union players [9]; injury risk increased linearly with one week loads and week-to-week changes in loads. In addition, a "U" shaped curve was found for Rugby

Union players; there was a likely beneficial reduction in injury risk associated with intermediate loads, and a likely harmful effect evident for lower and higher loads.

Recently, workload-performance investigations have examined absolute workload performed in 1-week (referred to as acute workload) relative to 4-week chronic workload (i.e., 4-week average acute workload) [10]. A four week chronic workload period is suited to Gaelic football given that most training programs are designed by coaches around 4 week cycles during the season. Ultimately the logic behind this workload ratio is to allow for a comparison of the acute (i.e. "fatigue) and chronic (i.e. fitness) phases of training. A comparison of the acute load to the chronic load as a ratio is therefore a dynamic representation of a player's preparedness. The ratio ultimately considers the training load the athlete has performed relative to the training load the athlete has been prepared for [11]. Using the acute:chronic workload ratio, it has been demonstrated that higher chronic workloads protected against injury in cricket [12]. Within Rugby League cohorts, higher workloads have been reported to have either positive or negative influences on injury risk. Specifically, compared with players who had a low chronic workload, players with a high chronic workload were more resistant to injury with moderate-low through moderate-high (0.85–1.35) acute:chronic workload ratios and less resistant to injury when subjected to 'spikes' in acute workload [12, 13].

Although associations between workload and injury have been shown in a select number of sports, it is likely that the workload-injury relationship is unique and specific to each individual sport. To date, workload has not been investigated as a modifiable risk factor for injury within Gaelic football. Accordingly, the current study aimed to investigate the relationship between workload measures and injury risk in elite Gaelic football players.

METHODS

Participants

The current investigation was a prospective cohort study of elite Gaelic football players competing at the highest level of competition in Gaelic football (National League Division 1 and All-Ireland). Data were collected for 37 players (Mean ± *SD*, age: 24 ± 6 years; height: 180 ± 7 cm; mass: 81 ± 7 kg) over one season. The senior level playing experience of the current squad was 8 ± 4 years. Playing experience within a Gaelic football context refers to the time a player is registered to the senior elite playing squad. Currently in Gaelic football, players can be released from elite squads to return to sub-elite competition where management see appropriate. The study was approved by the local institute’s research ethics committee and written informed consent was obtained from each participant.

Procedures

All time-loss injuries were recorded using a bespoke database for data collection. All injuries that prevented a player from taking full part in all training and match play activities typically planned for that day, and prevented participation for a period greater than 24 h were recorded. The current definition mirrors that employed by Brooks et al. [14] and conforms to the consensus time-loss injury definitions proposed for team sport athletes [15, 16, 17]. All injuries were classified as being low severity (1–3 missed training sessions); moderate severity (player was unavailable for 1–2 weeks); or high severity (player missed 3 or more weeks). Injuries were also categorised for injury type (description), body site (injury location) and mechanism [8].

Data were collected from 161 pitch and gym based training sessions from November through September. Each player participated in 2 to 3 pitch based training sessions depending on the week of the season. During the pre-season and early in-season period training sessions typically had elements of position specific fitness work in addition to technical and tactical elements. As the season progressed there was a focus towards increased technical and tactical work. This resulted in a reduction of fitness specific elements. The pitch based training sessions were supplemented by 2 gym based, strength training sessions per week. The duration of the pitch based training sessions was typically between 60 and 130 minutes depending on session goals. The typical gym based session of 60-70 minutes with both upper and lower body exercises within the program for players.

The intensity of all training sessions (including rehabilitation sessions) and match play were estimated using the modified Borg CR-10 rate of perceived exertion (RPE) scale, with ratings obtained from each individual player within 30 minutes of completing each training session [18]. Each player had the scale explained to them before the start of the season and players were asked to report their RPE for each session confidentially without knowledge of other players' ratings. Session-RPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration (min). Session-RPE has previously been shown to be a valid method for estimating exercise intensity [19, 20]. The aerobic fitness of players was assessed by conditioning staff during each phase of the season. Players completed a time trial (TT) over a set distance of 1 km, which is similar in nature to previously reported continuous running field tests [21, 22, 23], with players' final time used for the analysis of aerobic fitness.

The competitive season was divided into three distinct phases for descriptive purposes: 'pre-season' (between November and January) the 'early in-season' (February to June), and the 'late in-season' (July to September). In addition to weekly training load, a number of other training load measures were derived based on previous studies: (1) cumulative two, three and four weekly loads (2) the absolute change in load from the previous week (3) the acute:chronic workload ratio [11, 12, 13] (4) weekly training monotony (weekly mean/standard deviation) [9, 20]; (5) weekly training strain (weekly training load x training monotony) [9, 20].

Statistical Analysis

Data were analysed in SPSS Version 22.0 (IBM Corporation, New York, USA). Initial analysis of workload across phases took place using a repeated measure ANOVA. A chi-squared analysis was used to compare the frequency of injuries between seasonal phases, workloads in players with different elite level experience (1, 2–3, 4–6 and 7+ years) and fitness levels (1 km TT performance). Based on a total of 91 injuries from 3,515 player-sessions (37 players participating in 95 training sessions), the calculated statistical power to establish the association between internal loads and soft-tissue injuries was 85%. Weekly load exposure values and all injury data (injury vs. no injury) including, subsequent week injuries, were then modelled using a logistic regression analysis. Data were divided into four groups, with the lowest workload range being the reference group. Odds ratios (OR) were calculated to determine the injury risk at a given cumulative workload (1, 2, 3 and 4-weekly cumulative), acute:chronic workload ratio and for absolute change in workload (the previous to current week). Correlation coefficients between the training load measures, alongside Variance Inflation Factors (VIF), were used to detect multicollinearity between the predictor variables. A VIF of ≥10 was deemed indicative of substantial multicollinearity [24]. Within our model, all load measures provided a VIF of ≤ 10 therefore providing acceptable levels of multicollinearity. When an OR was greater than 1, an increased risk of injury was reported (i.e., OR = 1.50 is indicative of a 50% increased risk) and vice versa.

RESULTS

In total, 91 time-loss injuries were reported across the season (35 training injuries and 56 match injuries). This equates to 2.4 injuries per player. Overall, match injury incidence was 46.3/1000 hours, (95% CI: 43.9-53.8) and training injury incidence was 5.8/1000 hours

(95% CI: 4.8-6.8). The total match and training volumes reported during the season were 1,210 hours and 5,975 hours respectively (Table 1 and Table 2).

Absolute Workloads

There were no differences in average weekly workloads across the pre-season (2,580 ± 615 AU), early in-season (2,740 ± 610 AU), and late in-season (2,560 ± 603 AU) phases ($P = 0.112$). However, injury risk was phase dependant with a higher risk of injury during the late in-season compared to pre-season (Table 3). Players who exerted in-season 1-weekly loads of >1500 to 2700 AU were at significantly higher risk of injury compared to the reference group of <1200 AU (OR = 2.44, 95% CI 1.28–4.66, p = 0.006). Similarly, players who had completed an in-season 2-weekly and 3-weekly load of >3950 AU and >4750 AU were at significantly higher risk of injury compared to the reference group of <1950 AU (OR = 4.74, 95% CI 1.14–8.76, p = 0.033) and <2750 AU (OR = 6.11, 95% CI 4.26–8.14, p = 0.023) (Table 3).

Changes in Workloads

Injury risk during the pre-season (OR = 2.58, 95% CI 1.09–4.52, p = 0.001) and late in-season phase (OR = 7.42, 95% CI 6.41–8.12, p = 0.002) was higher for players who experienced a previous to current week change in load of >1000 AU compared to the reference group of <120 AU. Players who exerted in-season acute:chronic workload ratios of >1.35 to 1.50 (OR = 0.88, 95% CI 0.28–4.66, p = 0.006) were at significantly lower risk of injury compared to the reference group of < 1.00. There was a linear increase in injury risk for players who exerted late in-season acute:chronic workload ratios of >1.35 to 1.50 (OR = 3.25, 95% CI: 1.69–7.51, p = 0.006) and >2.00 (OR = 5.33, 95% CI: 1.69–6.75, p = 0.003) when compared to the reference group. However, players who exerted in-season acute:chronic workload ratios of >2.00 were at increased injury risk (OR = 3.33, 95% CI 1.69–6.65, p = 0.001) compared to the reference group < 1.00 (Table 3 and Table 4)

First year players had a significantly higher injury risk (OR = 3.12, 95% CI 2.16–3.93, p = 0.035) compared to the 7+ year reference group when experiencing an absolute 1-week load of >1750 AU, with other players having lower injury risk for similar workloads. When a previous to current week change in load of >550 AU to 1000 AU was applied, 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 elite Gaelic football experience were found to have a significantly lower risk of injury compared to the reference group. Additionally, when the acute:chronic workload ratio was > 1.50, first year players had a higher risk of injury (OR = 2.22, 95% CI 1.45-3.36, p = 0.009) and players with 2–3 (OR = 0.20, 95% CI 0.04–0.78, p = 0.009) and 4–6 years' experience (OR = 0.24, 95% CI 0.06–0.80, p = 0.045) had a significantly lower risk of injury (Tables 5).

When aerobic fitness was considered based on 1 km TT performance, players with a poor aerobic fitness had a higher risk of injury than the players with better-developed aerobic fitness (OR = 1.50-2.50, p = 0.009-0.011). The risk of injury was also higher in players with poor aerobic fitness at comparable absolute workloads, previous to current week change in workloads, and when the acute:chronic workload ratio was >1.50 (Table 6).

DISCUSSION

The current study is the first to investigate the association between training and game loads and injury risk in elite Gaelic football players. The presented data suggest that a positive linear association exists between weekly workload, absolute week-to-week changes in workload and subsequent injury risk during all phases of the season. The presented data further highlights that fewer years of playing experience and poorer aerobic fitness increase the risk of injury at a given training load. The findings of the current study suggest that weekly training load, absolute week-to-week changes in training load, 2-weekly, 3-weekly, 4-weekly cumulative loads and acute:chronic workload ratios should be monitored by elite

Gaelic football teams in order to reduce injury risk across all phases of the competitive season.

The injury risk of 2–3 (OR = 0.12) and 4–6 year players (OR = 0.22) was significantly lower than the reference group (7+ year players) when experiencing a previous to current week change in load of >550 - 1000 AU. This approximately equates to an average increase of training time of 1.5 – 3 hours at an average RPE of 6. In contrast to previous investigations [8], we also found that players with 1 year experience had the highest in-season risk compared to other age groups. These findings suggest that care should be taken when exposing players with limited experience to a large, previous to current week change in load. The increased injury risk may be related to the lack of transitional pathways for these younger players within Gaelic football and exposure to elite level training and match demands without prior experience of such loads or demands. Indeed, the gap between underage and elite adult competitive Australian football has previously been shown to be significant for distance covered and the percentage of time spent in sprinting actions [26]. Coaches should be cautious of the exposure of young novice players to elite adult training and match-play due to the increased risk of injury in these players.

We found that players with higher aerobic fitness (as estimated by better 1 km time trial performance) were at lower risk of injury during the in-season period compared with their less-fit counterparts (OR: 2.51-4.11). This is an important consideration as athletes who do not have the required physical qualities to tolerate the physiological demands of competition are likely to have reduced playing performance and increased injury risk. These findings are consistent with others [3, 7, 27] who have shown that well-developed physical qualities are associated with decreased injury risk in elite team based field sports [7]. The requirement of coaches to develop the physical capacity of players is of importance from both a performance and injury prevention perspective. Indeed, previous investigations have shown that reductions in workload can not only reduce injury risk but also improve aerobic capacity within team sport players [3, 7].

In agreement with recent findings from Australian football [8] and Rugby Union [9], absolute changes in week-to-week loads increased the risk of injury. An absolute change in load of >550 to 1000 AU was associated with a significant increase in the risk of injury the following week with this risk increasing across the phases of the season. Within the current investigation increases of this proportion during the late in-season phase were associated with greater risk (OR = 7.00) than similar magnitude changes in the early in-season phase (OR = 3.57). Sudden workload increases could be imposed on players during the late in-season phase due to coaching staff increasing technical and tactical skills to prepare players for the ‘All-Ireland’ series, which is deemed the most important stage of the season by both players and coaching staff. This study is in contrast to many other team sport investigations on player workloads where significant reductions in workload have been observed as the season progress [4, 8]. The increased risk in this late in-season period may be related to increased training and match running workloads in addition to previously injured players returning to high training demands before complete rehabilitation. Coaches and medical staff within elite Gaelic football should be aware that returning players are at increased risk due to a lack of an appropriate training stimulus from previous phases. As such future research within elite Gaelic football should investigate that application of the acute:chronic workload ratio in the return to play process. Previously this ratio has been shown to be applicable to the rehabilitation process within other team sports however, each team sport rehabilitation process has its own specific demands. Therefore the application of the acute:chronic workload ratio is warranted within a Gaelic football specific context [11].

The current study is the first to investigate the acute:chronic workload ratio within Gaelic football players and report threshold values for absolute changes in this ratio. The ratio indicates how the player's recent acute workload compares with the work completed during the preceding chronic period [12, 13, 14]. We found that this ratio was sensitive to injury risk. This risk was seasonal phase dependant with the greatest risk of injury in this study was displayed when the acute:chronic workload ratio exceeded 2.0 during all seasonal phases. Additionally the thresholds identified for the acute:chronic workload ratio had different sensitivity to injury risk depending on the phases of the season. For example players who had an acute:chronic workload ratio of ≥ 1.35 to ≤ 1.50 were at reduced risk of injury in comparison to the reference grouping during both the pre-season (OR = 0.88) and early in-season (0.88) periods however, players with the same acute:chronic workload ratio during the late in-season period were at increased risk in comparison to the reference group (OR = 3.25) Interestingly aerobic fitness impacted on the risk of injury. Players with a lower aerobic fitness were at an increased risk (OR = 5.10) of injury when the acute:chronic workload ratio was moderate-high in nature (≥ 1.35 to ≤ 1.50). Similarly, playing experience impacted the acute:chronic workload ratio; first year players were at increased risk of injury with moderate-high ratios compared to 2-3 year and 4-6 year players. Collectively, our findings highlight that injury risk in elite Gaelic footballers is influenced by aerobic fitness, playing experience, and the acute:chronic workload ratio. We recommend that training loads be manipulated according to aerobic fitness levels, phase of the season and playing experience while ensuring that low-moderate manipulations in acute:chronic workload are implemented to confer the protective effect of training.

Methodological Considerations

Factors in addition to training and match load, such as previous injury [5], perceived muscle soreness, fatigue, mood, sleep ratings [29] and psychological stressors [29], are likely to impact upon an individual's injury risk, however these were not accounted for in the current analysis. The day, week and phase of the season were reported clearly during the current investigation, however only total load values were collected. Unfortunately, it was not possible to describe the training loads of specific session types in this study. Additionally, whilst the session-RPE method has been proposed as an acceptable method of quantifying training load in team sports [30], GPS measures might provide important insight into the relationship between external training load and injury risk. Furthermore, there is a need to assess the utility of external:internal load ratios as a potential metric for injury risk assessment within team sports. Finally as with any analysis, the model will be best suited to the population from which it is derived. [17] One of the main limitations of the current investigation is that it is a one team and one season study, therefore it is difficult to translate these findings to other teams or across multiple seasons. Therefore, we recommend additional studies with a combination of Gaelic football squads to better understand the workload-injury relationship within the sport.

CONCLUSION

The current study is the first to show an association between workload measures and injury risk in elite Gaelic football players. Players were at an increased risk of injury if they had a high one week cumulative workload or large week-to-week changes in workload. A phase dependant association between all cumulative load measures and injury risk was identified with increased risk of injury as the season progressed. Our findings demonstrate that high acute:chronic workload ratios (>2.0) increase the risk of injury, while moderate-high acute:chronic workload ratios (≥ 1.35 to ≤ 1.50) protect against injury during the pre-season and early in-season periods. Both poor aerobic fitness and low playing experience were identified as risk factors for injury. Training and game loads and week-to-week changes in load should be individually monitored to reduce the risk of injury in elite Gaelic football players.

PRACTICAL APPLICATIONS

The current study is the first to find substantial associations between aerobic fitness, playing experience and injuries in elite Gaelic football players. High acute:chronic workload ratios (>2.0) and large absolute changes in workloads were associated with increased injury risk in this cohort. Interestingly, moderate-high acute:chronic workload ratios (≥ 1.35 to ≤ 1.50) appear to provide a protective effect for players against injury during the pre-season and early in-season periods but not the late in-season period. For the first time in Gaelic football playing experience was found to protect players against injuries. Given the cost effective nature of training monitoring using the session-RPE method, the above findings highlight the important role of medical, rehabilitation and sport science staff in improving player availability and potentially a team's chances of success. Therefore coaches, medical, rehabilitation, and strength and conditioning staff should be aware that as the Gaelic football season progresses, Gaelic football players are at an increased risk of injury. Even subtle changes in training load appear to increase injury risk. Knowledge of the risk of subtle absolute changes in training load may be useful when attempting to communicate the value of injury prevention initiatives within this elite sport setting (e.g. to coaches and administrative staff). Finally we recommend that coaches, medical, rehabilitation, and strength and conditioning staff should endeavour to work together in an interdisciplinary fashion to best plan training loads for elite Gaelic football players.

AKNOWLEDGEMENTS

The authors would like to acknowledge with considerable gratitude the players, coaches and medical staff for their help throughout the study period.

COMPETING INTERESTS

None declared

FUNDING

No external funding was provided for the current investigation.

CONTRIBUTOR STATEMENT

SM, MR, KC and DD conceived and designed the study. SM and MR were involved in the collection of injury and exposure data. SM and MR analysed the data. SM wrote the first and last draft of the manuscript. TJG, DD and KC assisted in the drafting of the document. All authors provided substantial contributions to the redrafting of the manuscript. All authors read and approved the final version of the manuscript.

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"Aerobic Fitness and Playing Experience Protect Against Spikes in Workload: The Role of the Acute:Chronic Workload Ratio on Injury Risk in Elite Gaelic Football" by Malone S et al.
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Table 1. Classification of pre-season, early in-season and late in-season injuries. Mean injury incidence reported per 1000 training and game hours (95% CI).

	Pre-Season (2395 hr)			Early-In Season (2645 hr)			Late In-Season (2145 hr)			Overall (7185 hr)		
	Number	Injury Incidence	%	Number	Injury Incidence	%	Number	Injury Incidence	%	Number	Injury Incidence	%
	20	9.50 (7.40 to 10.63)	21.9	32	12.10 (11.45 to 12.66)	35.1	39	18.20 (17.45 to 18.98)	42.8	91	12.67 (11.69 to 13.64)	100
Injury Site												
Lower Limb	19	7.93 (5.66 to 9.93)	95	27	10.21 (8.45 to 12.33)	84	35	16.32 (15.89 to 17.15)	90	81	11.27 (10.47 to 11.87)	89
Pelvis/Groin	3	1.25 (0.15 to 3.26)	15	2	0.76 (0.34 to 1.12)	6	5	2.33 (1.84 to 2.84)	13	10	1.39 (0.87 to 1.56)	11
Hip	0	0.00	0	3	1.13 (0.84 to 2.33)	9	6	2.80 (2.32 to 3.15)	15	9	1.25 (0.23 to 3.36)	10
Anterior Thigh	3	1.25 (0.23 to 3.36)	15	2	0.76 (0.54 to 1.12)	6	5	2.33 (1.84 to 2.84)	13	10	1.39 (0.87 to 1.56)	11
Posterior Thigh	6	2.86 (1.15 to 3.99)	30	11	4.16 (3.41 to 6.15)	34	12	5.59 (4.41 to 5.84)	31	29	4.04 (3.47 to 4.33)	32
Knee	3	1.43 (0.33 to 2.66)	15	2	0.76 (0.41 to 1.12)	6	2	0.93 (0.23 to 1.23)	5	7	0.97 (0.41 to 1.33)	8
Calf	1	0.48 (0.21 to 1.66)	5	3	1.13 (0.36 to 1.66)	9	1	0.47 (0.15 to 0.75)	3	5	0.70 (0.45 to 1.66)	5
Shin	0	0.00 (0.00 to 0.00)	0	1	0.38 (0.12 to 1.14)	4	1	0.47 (0.15 to 0.75)	3	2	0.28 (0.12 to 1.12)	2
Ankle	3	1.43 (0.33 to 2.56)	15	3	1.13 (0.74 to 1.69)	9	3	1.40 (1.14 to 1.65)	7	9	1.25 (0.47 to 1.66)	10
Upper Limb	1	0.48 (0.23 to 1.89)	5	5	1.89 (1.11 to 2.33)	15	5	2.33 (1.74 to 2.54)	13	10	1.39 (0.87 to 1.56)	11
Shoulder	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
Wrist	0	0.00	0	3	1.13 (0.84 to 2.33)	9	5	2.33 (1.74 to 2.54)	13	8	1.11 (0.84 to 2.23)	9
Finger/Thumb	0	0.00	0	2	0.76 (0.54 to 1.12)	6	0	0.00	0	2	0.28 (0.11 to 0.54)	2
Head/Neck												
Head	1	0.48 (0.12 to 1.33)	5	1	0.38 (0.12 to 1.11)	3	0	0.00	0	2	0.28 (0.11 to 0.54)	2
Eye	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
Tissue												
Muscle	7	3.34 (1.25 to 4.34)	35	12	4.54 (3.15 to 5.66)	38	16	7.46 (6.54 to 8.15)	41	35	4.87 (4.15 to 5.47)	38
Tendon	6	2.86 (0.99 to 4.15)	30	6	2.27 (1.84 to 3.14)	19	7	3.26 (2.74 to 3.56)	18	19	2.64 (1.74 to 2.99)	21
Ligament	5	2.39 (1.11 to 3.56)	25	6	1.89 (0.44 to 2.16	19	7	3.26 (2.74 to 3.56)	18	18	2.51 (2.11 to 3.41)	20
Joint (General)	1	0.48 (0.21 to 1.66)	5	1	0.38 (0.11 to 0.99)	3	0	0.00	0	2	0.28 (0.11 to 0.54)	2
Bone (Fracture)	0	0.00	0	3	1.13 (0.84 to 2.33)	9	3	1.40 (0.99 to 1.66)	7	6	0.84 (0.41 to 1.26)	7
Bone (Bruising)	1	0.48 (0.22 to 1.74)	5	4	1.51 (1.23 to 1.84)	12	4	1.86 (1.54 to 2.19)	10	9	1.25 (0.84 to 1.55)	10
Haematoma	0	0.00	0	0	0.00	0	2	0.93 (0.84 to 1.33)	5	2	0.28 (0.11 to 0.54)	2
Activity												
Training (5,975 hr)	8	1.33 (1.13 to 4.15)	40	12	2.00 (1.14 to 3.44)	38	15	2.51 (1.05 to 3.36)	39	35	5.85 (4.85 to 6.85)	38
Match Play (1,210 hr)	12	9.91 (7.15 to 10.33)	60	20	16.52 (14.84 to 18.45)	63	24	19.83 (18.84 to 21.69)	62	56	46.39 (43.90 to 53.85)	62
Injury Type												
New	15	7.16 (4.15 to 8.13)	75	26	9.83 (9.15 to 10.12)	81	29	13.52 (12.84 to 13.66)	74	70	9.74 (9.26 to 10.23)	77
Recurrent	5	2.39 (0.89 to 4.15)	15	6	2.27 (1.84 to 3.14)	19	10	4.66 (4.02 to 5.26)	26	21	2.92 (2.14 to 3.15)	23

Table 2. Classification of pre-season, early in-season and late in-season injuries. Mean injury incidence reported per 1000 game and training hours (95% CI).

	Pre-Season (2395 hr)			Early-In Season (2645 hr)			Late In-Season (2145 hr)			Overall (7185 hr)		
	Number	Injury Incidence	%	Number	Injury Incidence	%	Number	Injury Incidence	%	Number	Injury Incidence	%
	20	9.50 (7.40 to 10.63)	21.9	32	12.10 (11.45 to 12.66)	35.1	39	18.20 (17.45 to 18.98)	42.8	91	12.67 (11.69 to 13.64)	100
Side of Injury												
Bilateral	2	0.95 (0.12 to 1.45)	10	1	0.38 (0.21 to 0.64)	3	1	0.47 (0.22 to 0.75)	3	4	0.56 (0.12 to 0.88)	4%
Left	8	3.82 (1.99 to 4.99)	40	14	5.29 (4.15 to 6.68)	44	18	8.39 (8.02 to 9.25)	46	40	5.57 (5.32 to 5.84)	44%
Right	10	4.77 (2.14 to 5.66)	50	17	6.43 (5.14 to 7.66)	53	20	9.32 (8.69 to 9.85)	51	47	6.54 (5.99 to 7.12)	52%
Timing of Injury												
Quarter 1	1	0.48 (0.22 to 1.74)	5	3	1.13 (0.84 to 1.45)	9	3	1.40 (1.11 to 1.66)	8	7	0.97 (0.12 to 1.66)	8%
Quarter 2	4	1.91 (0.84 to 2.66)	20	5	1.89 (1.45 to 2.15)	16	6	2.80 (2.45 to 3.26)	15	15	2.09 (1.84 to 2.66)	16%
Quarter 3	7	3.34 (1.84 to 4.18)	35	13	4.91 (4.12 to 5.66)	41	15	6.99 (6.15 to 7.66)	38	35	4.87 (4.21 to 5.35)	38%
Quarter 4	8	3.82 (2.15 to 4.66)	40	11	4.16 (3.74 to 4.66)	34	15	6.99 (6.15 to 7.66)	39	34	4.73 (3.84 to 5.66)	37%
Severity												
Low (1 -3 training sessions)	5	2.39 (1.45 to 3.56)	25	8	3.02 (2.45 to 3.45)	25	10	4.66 (3.84 to 5.15)	26	23	3.20 (2.74 to 3.84)	25%
Moderate (1-2 weeks)	10	4.77 (3.99 to 5.45)	50	16	6.05 (5.13 to 7.12)	50	19	8.86 (8.06 to 9.66)	76	45	6.26 (5.75 to 7.53)	49%
High (3+ weeks)	5	2.39 (1.45 to 3.56)	25	8	3.02 (2.45 to 3.45)	25	10	4.66 (4.05 to 4.86)	26	23	3.20 (2.84 to 3.44)	25%
Mechanism												
Contact	2	0.95 (0.45 to 1.66)	10	5	1.89 (1.19 to 2.74)	16	4	1.86 (1.75 to 2.15)	10	11	1.53 (1.15 to 1.77)	12%
Non-Contact	18	8.59 (7.45 to 10.12)	90	27	10.21 (9.45 to 10.86)	84	35	16.32 (15.84 to 16.84)	90	80	11.13 (10.47 to 11.45)	89%

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Table 3. Seasonal phase risk factors for injury for 1-week, 2-week, 3-week, and 4-week cumulative training and game load in elite Gaelic footballers. Data presented as OR (95% CI).

	Training Load Component	Pre-Season (Nov -Jan)	Early In-Season (Feb - June)	Late In-Season (July - Sept)
Cumulative Load (Sum)		**OR EXP B (95% CI)**	**OR EXP B (95% CI)**	**OR EXP B (95% CI)**
	RPE (AU)			
	1-Weekly			
	≤ 1200 AU (Reference)	1.00	1.00	1.00
	Between 1200 AU to ≤ 1500 AU	1.95 (0.98 - 3.95)	3.95 (1.24 - 5.12)	1.95 (0.88 - 3.84)
	Between ≥ 1500 AU to ≤ 2700 AU	2.44 (1.98 - 4.66)	1.99 (1.77 - 3.22)	1.99 (1.44 - 4.55)
	≥ 2700 AU	3.33 (1.69 - 6.75)	4.33 (2.15 - 6.12)	8.33 (7.45 - 9.44)
	2-Weekly			
	≤ 1950 AU (Reference)	1.00	1.00	1.00
	Between 1950 AU to ≤ 2950 AU	2.98 (1.98 - 3.85)	2.98 (2.15 - 4.98)	3.98 (1.66 - 4.54)
	Between ≥ 2950 AU to ≤ 3950 AU	4.03 (2.11 - 7.45)	5.03 (3.15 - 5.12)	4.01 (2.01 - 6.22)
	≥ 3950 AU	4.74 (2.74 - 8.66)	7.44 (4.12 - 9.44)	6.44 (4.12 - 7.44)
	3-Weekly			
	≤ 2750 AU (Reference)	1.00	1.00	1.00
	Between 2750 AU to ≤ 3750 AU	3.88 (2.47 - 6.55)	9.55 (7.66 - 9.66)	4.55 (2.45 - 6.22)
	Between ≥ 3750 AU to ≤ 4750 AU	5.11 (3.11 - 7.65)	7.44 (4.23 - 9.66)	6.84 (4.84 - 8.66)
	≥ 4750 AU	6.11 (4.26 - 8.14)	9.11 (7.45 - 9.33)	9.11 (7.26 - 10.11)
	4-Weekly			
	≤ 3550 AU (Reference)	1.00	1.00	1.00
	Between 3550 AU to ≤ 4550 AU	5.11 (4.12 - 7.45)	5.21 (2.74 - 8.66)	4.33 (2.33 - 6.12)
	Between ≥ 4550 AU to ≤ 5550 AU	7.44 (4.23 - 9.14)	6.11 (3.84 - 8.12)	7.11 (6.12 - 9.12)
	≥ 5550 AU	8.11 (6.22 - 9.25)	9.11 (7.45 - 9.33)	10.22 (8.22 - 12.11)
	Absolute Change from previous week			
	≤ 120 AU (Reference)	1.00	1.00	1.00
	Between 120 AU to ≤ 250 AU	0.89 (0.50 - 1.98)	2.95 (1.02 - 3.99)	4.55 (2.12 - 5.42)
	Between ≥ 250 AU to ≤ 550 AU	1.66 (0.90 - 2.21)	1.99 (0.98 - 2.98)	6.54 (4.12 - 8.12)
	Between ≥ 550 AU to ≤ 1000 AU	2.44 (2.01 - 4.25)	3.54 (1.33 - 6.15)	7.00 (5.84 - .9.25)
	≥ 1000 AU	2.58 (1.09 - 4.52)	5.33 (2.74 - 8.66)	7.42 (6.41 - 9.96)

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Table 4. Seasonal phase risk factors for injury for acute:chronic workload ratio in elite Gaelic footballers. Data presented as OR (95% CI).

	Training Load Component	**Pre-Season (Nov -Jan)**	**Early In-Season (Feb - June)**	**Late In-Season (July - Sept)**
Cumulative Load (Sum)		**OR EXP B (95% CI)**	**OR EXP B (95% CI)**	**OR EXP B (95% CI)**
	Acute:Chronic Workload Ratio			
	≤ 1.00 (Reference)	1.00	1.00	1.00
	Between 1.00 to ≤ 1.35	1.95 (0.98 - 3.95)	1.95 (0.98 - 3.95)	2.95 (0.98 - 3.95)
	Between ≥ 1.35 to ≤ 1.50	0.88 (0.28 - 4.66)	0.88 (0.28 - 4.66)	3.25 (1.69 - 7.51)
	≥ 2.00	3.33 (1.69 - 6.75)	4.33 (1.69 - 6.75)	5.33 (1.69 - 6.75)

Table 5. Elite Gaelic football experience levels as a risk factor for injury above certain training and game load values. Data presented as OR (95% CI) when compared to a reference group.

Load Calculation	In-Season			
	OR Exp (B)	95% Confidence Interval Lower	95% Confidence Interval Upper	p-Value
Cumulative load (sum)				
1-week				
>1750 AU				
7+ years experience	1.00			
1 Year	3.12	2.16	3.93	0.035
2 to 3 years	0.12	-0.25	0.89	0.236
4 to 6 years	0.22	0.10	0.99	0.336
Absolute Change (±)				
Previous to Current Week				
>550AU to 1000 AU				
7+ years experience	1.00			
1 Year	2.12	1.56	2.36	0.021
2 to 3 years	0.22	0.07	0.68	0.009
4 to 6 years	0.28	0.10	0.80	0.020
Acute:Chronic Workload Ratio				
>1.50				
7+ years experience	1.00			
1 Year	2.22	1.45	3.36	0.009
2 to 3 years	0.20	0.04	0.78	0.045
4 to 6 years	0.24	0.06	0.80	0.033

Table 6. Elite Gaelic football fitness levels as determined by a 1 km TT as a risk factor for injury above certain training and game load values. Data presented as OR (95% CI) when compared to a reference group.

Load Calculation	In-Season			
	OR	95% Confidence Interval		p-Value
	Exp (B)	Lower	Upper	
Cumulative load (sum)				
1-week				
>1750 AU				
3.00 to 3.15 min	1.00			
3.16 to 3.30 min	2.51	1.99	2.99	0.009
3.31 to 3.45 min	2.48	2.16	3.93	0.035
3.46 to 4.00 min	4.50	3.98	5.50	0.033
Absolute Change (±)				
Previous to Current Week				
>550AU to 1000 AU				
3.00 to 3.15 min	1.00			
3.16 to 3.30 min	1.54	0.98	1.99	0.009
3.31 to 3.45 min	2.53	2.08	2.92	0.011
3.46 to 4.00 min	4.52	3.98	4.92	0.023
Acute:Chronic Workload Ratio				
>1.50				
3.00 to 3.15 min	1.00			
3.16 to 3.30 min	1.02	0.26	2.59	0.425
3.31 to 3.45 min	2.48	1.50	4.98	0.045
3.46 to 4.00 min	5.10	3.98	8.10	0.033