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High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football.

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ABSTRACT

Objectives: To examine the relationship between chronic training loads, number of exposures to maximal velocity, the distance covered at maximal velocity, percentage of maximal velocity in training and match-play and subsequent injury risk in elite Gaelic footballers.

Design: Prospective cohort design

Methods: Thirty-seven elite Gaelic footballers from one elite squad were involved in a one-season study. Training and game loads (session-RPE multiplied by duration in min) were recorded in conjunction with external match and training loads (using global positioning system technology) to measure the distance covered at maximal velocity, relative maximal velocity and the number of player exposures to maximal velocity across weekly periods during the season. Lower limb injuries were also recorded. Training load and GPS data were modelled against injury data using logistic regression. Odds ratios (OR) were calculated based on chronic training load status, relative maximal velocity and number of exposures to maximal velocity with these reported against the lowest reference group for these variables.

Results: Players who produced over 95% maximal velocity on at least one occasion within training environments had lower risk of injury compared to the reference group of 85% maximal velocity on at least one occasion (OR: 0.12, $p = 0.001$). Higher chronic training loads (≥ 4750 AU) allowed players to tolerate increased distances (between 90 to 120 m) and exposures to maximal velocity (between 10 to 15 exposures), with these exposures having a protective effect compared to lower exposures (OR: 0.22 $p = 0.026$) and distance (OR = 0.23, $p = 0.055$).

Conclusions: Players who had higher chronic training loads (≥ 4750 AU) tolerated increased distances and exposures to maximal velocity when compared to players exposed to low chronic training loads (≤ 4750 AU). Under- and over-exposure of players to maximal velocity events (represented by a U-shaped curve) increased the risk of injury.

Key Words: Injury prevention, Team sport, Odds ratios, Maximal velocity distance

INTRODUCTION

Training load has been reported as a modifiable risk factor for subsequent injury [1]. Several studies have investigated the influence of training workload and injury risk in team sports. In professional rugby union, players [1] higher 1-week (> 1245 AU) and 4-week cumulative loads (> 8651 AU) were associated with a greater risk of injury. Furthermore, Rogalski et al. [2] observed that larger 1-weekly (>1750 arbitrary units, OR= 2.44–3.38), 2-weekly (>4000 arbitrary units, OR= 4.74) and previous to current week changes in load (>1250 arbitrary units, OR = 2.58) were significantly related to greater injury risk throughout the in-season phase in elite Australian rules football players.

The ability to produce high speeds is considered an important quality for performance, with athletes shown to achieve 85-94% of maximal velocity during team sport match-play [3]. Well-developed high-speed running ability and maximal velocity are required of players during competition in order to beat opposition players to possession and gain an advantage in attacking and defensive situations [4,5]. In order to optimally prepare players for these maximal velocity and high speed elements of match play, players require regular exposure to periods of high-speed running during training environments [6] in order to attain high percentages of maximal velocity. Recent evidence suggests that lower limb injuries are associated with excessive high-speed running exposure [7,8]. Within elite rugby league and Australian football cohorts, players who performed greater amounts of very high-speed running within training sessions were 2.7 and 3.7 times more likely to sustain a non-contact, soft tissue injury than players who performed less very-high speed running [8,9]. However, these studies failed to assess the potential impact that chronic training load could have on reducing the injury risk in these players. Currently there is a lack of understanding of the potential benefits of maximal velocity exposures and also the minimum dose required to provide protection against injuries.

Recent evidence suggests that high chronic training loads can offer a protective stimulus for team sport athletes [10,11]. Australian rules football players with higher 1 week training loads (> 3519 AU) were at reduced risk of injury (OR = 0.199) compared to players exposed to lower training loads (< 3518 AU) [12]. Additionally Cross et al. [1] have reported a U-shaped curve for training load and injury risk in elite rugby union players with low and high training loads increasing injury risk, and intermediate loads reducing injury risk. High aerobic fitness has been reported to offer a protective effect against subsequent lower limb injury for team sport players [6]. Higher training loads may be needed to provide the appropriate stimulus for aerobic fitness improvements [6] with lower training loads potentially placing players at increased risk due to a lack of exposure to the physical stimulus required for competitive play [6].

Although greater amounts of high-speed running have been associated with injury risk, there is evidence that players are often required to perform maximal efforts over short to moderate distances during competition and training [3, 8, 13, 14, 15]. Training for team sport ultimately requires a balance between appropriately prescribed training loads to develop the required physical qualities to compete while also allowing the appropriate recovery between sessions and match-play to minimise injury risk for players. Given the need for players to perform maximal efforts during match-play, exposure of players to these maximal efforts during training may offer a "vaccine" against soft-tissue injury [6]. However, the inter-relationship among these training variables and potential injury risk is poorly understood. Therefore the aim of the current investigation was to examine exposure to maximal velocity events as a potential modifiable risk factor for injury within Gaelic football. Additionally with higher chronic training loads offering a protective effect from injury in other sports, there is a need to investigate the interaction of chronic training loads, maximal velocity exposure, and injury risk within Gaelic football. Accordingly, we explored the relationship between training load, the number of maximal velocity exposures during training and match-play, the distance covered at maximal velocity and injury risk in elite Gaelic football players.

METHODS

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 Championship). Data were collected for 37 players (Mean ± *SD*, age: 24 ± 3 years; height: 179 ± 5 cm; mass: 79 ± 7 kg) over one season. The study was approved by the local institute's research ethics committee and written informed consent was obtained from each participant.

The intensity of all competitive match-play and training pitch based sessions (including recovery and rehabilitation sessions) 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 the match or training session [16]. Each player was asked to report their RPE for each session confidentially without knowledge of other players' ratings. Each individual player's session RPE in arbitrary units (AU) was then derived by multiplying RPE and session duration (min) [16]. Session-RPE (sRPE) has previously been shown to be a valid method for estimating exercise intensity [17]. sRPE was then used to calculate 4-week chronic workload (i.e., 4-week average acute workload) [18, 19].

Maximal velocity running and exposure to maximal velocity during all sessions was monitored using global positioning system (GPS) technology (VXSport, Lower Hutt, New Zealand) providing data at 4-Hz. Players were assigned individual units that were worn across all sessions to account for any inter-unit variability. Initially players' individual maximal velocity was assessed during a maximal velocity test. During the test, dual beam electronic timing gates were placed at 0-, 10-, 20-, 30-and 40-m (Witty, Microgate, Bolzano, Italy). Speed was measured to the nearest 0.01 seconds with the fastest value obtained from 3 trials used as the maximal velocity score. The calculated velocity between the 20 and 40 m gates was used as a measure of maximal velocity [20]. The intra-class correlation coefficient for test-retest reliability and typical error of measurement for the 10, 20, 30 and 40 m sprint tests were 0.95, 0.97, 0.96 and 0.97 and 1.8, 1.3, 1.3 and 1.2%, respectively. Analysis of calculated speeds revealed a significant correlation (r = 0.85, p = 0.02) between GPS and timing gate measures, with no significant difference between measures of speeds measured by the timing gates (31.2 $km \cdot h^{-1}$) and GPS measures (31.0 $km \cdot h^{-1}$) (p = 0.842) therefore allowing for maximal velocity to be tracked with a high degree of accuracy with the GPS system. Maximal velocity exposures were recorded when a player covered any distance (m) at their own individualised maximal velocity ($km \cdot h^{-1}$) during training or match-play events. If a player produced a maximum velocity in training or match-play that exceeded the test value, this became the players' new maximum velocity for the period. During this period, the players' ability to produce maximal velocity was also tracked in relative terms by expressing data as a percentage of their maximal velocity. Therefore during this observational period, players' number of maximal velocity exposures, the distance covered at maximal velocity and their relative maximal velocity were tracked over weekly periods throughout the whole season in line with the internal and external training load measures. Training load (sRPE), maximal velocity distance, the number of maximal velocity exposures and the percentage of maximal velocity achieved were then analysed across acute 1-weekly workload periods

(Monday - Sunday). Acute workload periods were compared to the chronic training load over the same period (previous 4-week average acute workload) [19].

All GPS and lower limb soft tissue injuries were classified into acute 1-weekly blocks and chronic 4-weekly blocks using a bespoke database. Data were collected from 95 pitch 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. The pitch based training sessions were supplemented by 2 gym based, strength training sessions. The duration of the pitch based training sessions was typically between 60 and 130 minutes depending on session goals. 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 of injury mirrors that employed by Brooks et al. [21] and conforms to the consensus time loss injury definitions proposed for team sport athletes [22,23]. All injuries were further 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 [2].

SPSS Version 22.0 (IBM Corporation, New York, USA) and R (version 2.12.1) software were used to analyze the data. Descriptive statistics were expressed as means ± SD and 95% confidence intervals of maximal velocity running loads and the number of maximal velocity exposures during the season. Injury incidence was calculated by dividing the total number of injuries by the total number of training hours and match hours. These hours were then expressed as a rate per 1,000 hours. The 95% confidence intervals (CIs) were calculated using the Poisson distribution, and the level of significance was set at $p \leq 0.05$. Maximal velocity exposure values and injury data (injury vs. no injury) were then modelled using a logistic regression analysis with adjustment for intra-player cluster effects. Data were initially split into quartiles (four even groups), with the lowest training load range used as the reference group. This was completed for relative maximal velocity, weekly maximal velocity distance and the total number of maximal velocity exposures. Additionally, to better understand the impact of previous chronic training load on maximal velocity running, training data was divided into low (≤ 4750 AU) and high (≥ 4750 AU) chronic training load groups using a dichotomous median split. Maximal velocity distance, maximal velocity exposures, and injury data were summarised at the completion of each week. Acute and chronic training load were calculated as described previously [19]. Previous training load history was then associated with players' tolerance to maximal velocity distance, maximal velocity exposures and injuries sustained in the subsequent week.. Players who sustained an injury were removed from analysis until they were medically cleared to return to full training. Odds ratios (OR) were calculated to determine the injury risk at a given relative percentage of maximal velocity, chronic training load, number of maximal velocity exposures, and distance covered (m) at maximal velocity. 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. Based on a total of 91 injuries from 3,515 player-sessions, the calculated statistical power to establish the relationship between running loads and soft-tissue injuries was 85%.

RESULTS

In total, 91 time-loss injuries were reported across the season (36 training injuries and 55 match injuries). A rate of 2.4 injuries per player was observed. Overall, match injury incidence was 45.3/1000 hours (95% CI: 41.9-53.8) with a training injury incidence of 6.9/1000 hours (95% CI: 5.8-7.8). The total match and training volumes reported during the season were 1,210 hours and 5,975 hours respectively.

Players who produced over 95% maximal velocity within training and match-play environments in the preceding week had a lower risk of injury than those who produced lower maximal velocity (OR: 0.12, 95% CI 0.01-0.92, p = 0.001) (Table 1). On average, players were exposed to maximal velocity 7 ± 4 times during match play and training environments; specifically players experienced 4 ± 3 exposures during training environments and 3 ± 1 exposures during match-play environments. When considered independent of chronic training load, a higher risk of injury was observed with both a lower and higher number of maximal velocity exposures (OR = 4.74, 95% CI 1.14–8.76, p = 0.023) (Figure 1).

The average session training load was 695 ± 136 AU during the study period, with an average acute weekly training load of 3475 ± 596 AU. When previous training load was considered, players with a higher chronic training load (≥ 4750 AU) were able to tolerate increased exposures to maximal velocity (between 10 to 15 exposures) events, with these having a protective effect compared to lower exposures (OR: 0.22 95% CI 0.10-1.22 p = 0.026). Players with a lower chronic training load (≤ 4750 AU) were at increased injury risk

(OR: 1.44 95% CI 1.28-2.22, $p = 0.107$) when exposed to similar maximal velocity events (between 10 to 15 exposures) (Table 2)

The average seasonal 1-weekly running distance covered at maximal velocity was 170 ± 69 m. Players who exerted higher chronic training loads (≥ 4750 AU) were at significantly reduced risk of injury when they covered 1-weekly maximal velocity distances of 90 to 120 m compared to the reference group of < 60 m (OR = 0.23, 95% CI 0.10–1.33, $p = 0.055$). Conversely, players who had exerted low chronic training loads (≤ 4750 AU) and covered the same distance of 90 to 120 -m were at significantly higher risk of injury compared to the reference group of < 60 m (OR = 1.72, 95% CI 1.05–2.47, $p = 0.016$) (Table 3).

DISCUSSION

The current investigation is the first to explore the relationship between training load, maximal velocity exposures and injury risk in elite Gaelic football players. Our data showed that when players' produced over 95% of their maximal velocity they were at reduced risk of subsequent injury (OR: 0.12) (Table 1). When maximal velocity exposures were considered independently of training load history a U-shaped curve was shown for number of exposures and subsequent injury risk (Figure 1). Interestingly, the number of exposures required to offer a ''vaccine'' for subsequent injuries was related to the previous chronic load performed by players. The current investigation showed that a higher chronic training load (≥ 4750 AU) allows greater exposure to maximal velocity running which in turn offers a protective effect against injury. However, players with a low chronic load (≤ 4750 AU) were at increased injury risk at similar maximal velocity exposures. Our data highlight that the ability to expose players to their maximal velocity is a function of their chronic training load history with maximal velocity exposure protective for players when combined with higher training loads. Practically, our data suggest that players should be exposed to periods of training that best prepare them to attain higher velocity movements.

Our study is the first to investigate the impact of maximal velocity exposure on subsequent injury risk in an elite cohort of Gaelic football players. We observed that players who produced ≥ 95% of their maximal velocity were at reduced injury risk compared to players who produced lower relative maximal velocities (OR: 0.12). In addition, our findings suggest that players with moderate exposures to maximal velocity (> 6 to 10) were at reduced injury risk compared to players who experienced lower (< 5) exposures (OR: 0.24).

Conversely, players who experienced maximal velocity exposures of >10 were at a significantly higher risk of injury compared to the reference group. The current data suggests that moderate exposure to maximal velocity running can protect players from subsequent injury risk. Previous literature has supported the fact that a moderate exposure to high intensity periods can offer a protective effect for team sport players. Colby et al. [9] highlighted that players who covered moderate 3-week sprint distances (864-1,453 m) had lower injury risk compared to lower and higher volume groups. Our findings support the exposure of players to these maximal efforts within training situations to ensure they are adequately prepared for critical moments of match-play.

We found that players with higher chronic loads (≥ 4750 AU) experienced increased exposures to maximal velocity, with this increase in exposure offering a protective effect against injury. This might be explained by these players being exposed to previous training load that improved their ability to tolerate subsequent load, ultimately reducing their risk of injury. In contrast, players with low chronic loads where at greater risk of injury when exposed to the same number of maximal velocity exposures, perhaps reflecting the consequences of inadequate exposure to a sufficient workload over the previous period. Our results are in line with previous investigations from rugby league that have suggested that higher chronic loads protect against injury [10]. Therefore coaches should consider that the prescription of training that emphasises reductions in training load may actually increase athlete's susceptibility to injury due to inadequate chronic loads and fitness levels [6, 24]. However, coaches need to be aware that high chronic workloads, combined with large spikes in acute workload have previously demonstrated the greatest risk of injury in team sport players [10]; this would appear to be an important consideration when increasing training loads in order to return players to competitive play.[25] Coaches should be aware that although exposure to maximal velocity has a protective effect, players with higher chronic training loads are better prepared to tolerate subsequent maximal velocity load.

The current data has shown that depending on previous chronic training load status players can tolerate more intense periods of training. Players with higher chronic training loads were able to cover increased weekly distances (120 to 150 m) at maximal velocity with lower subsequent injury risk (OR: 0.26). Interestingly players with lower chronic loads were at increased risk of subsequent injury (OR: 3.12) at the same weekly running load (120 to 150 m). The current data provides information that advocates players covering moderate distance at their individual maximal velocity. Coaches must be aware that players need to have the necessary physical qualities in order to tolerate the exposures to maximal running volumes [6] as highlighted by the difference between low and high chronic load groupings. This is supported by previous observations [8] which found that players who covered more distance at very-high speed (> 9 m) suffered less time loss from injury when compared to those who covered less than 9 m. Finally, those players who covered greater absolute distances at high-speeds (> 190 m) missed fewer matches than players who covered less distance at the same thresholds [8].

There are some limitations of this study that should be considered. Firstly, all conditioning workloads (cross-training and strength training) cannot be quantified through the use of GPS technology. Research incorporating these objective measures with RPE-values and other data such as perceived muscle soreness, fatigue, mood, and sleep ratings [2, 26, 27] may provide additional insight into the training load–injury relationship of elite Gaelic football players. Additionally, we acknowledge that the players' injury history was not considered and is recognised as an important factor in subsequent injury incidence [6,26]. Finally although acceptable validity and accuracy was reported for the specific GPS units used within the current study, it should be noted that previous research has questioned the accuracy of GPS for the measurement of high speed movements [28]. To reduce injury risk in Gaelic football the application of maximal velocity exposures, relative maximal velocity and distance covered at maximal velocity should be considered when monitoring and modifying players weekly workload on an individual basis.

CONCLUSION

In conclusion when maximal velocity exposures were considered independently of training load history a U-shaped curve was shown for number of exposures and subsequent injury risk. Our data suggests that players who produce ≥ 95% of their maximal velocity were at reduced injury risk compared to players who produced lower relative maximal velocities. Coaches should expose players to high percentages of maximal velocity within training situations as this offers a potential ‘‘vaccine’’ against subsequent soft tissue injury. Players with higher chronic training loads (≥ 4750 AU) were able to cover increased weekly distances (120 to 150 m) at maximal velocity with lower subsequent injury risk, while players with lower chronic loads were at increased risk of subsequent injury at the same weekly running load. Coaches should be aware that players need to partake in hard but well planned training to be protected from subsequent injury. Finally, our findings suggest that exposure of players to maximal velocity running should be mainstream practice in elite sport in order to adequately prepare players for the demands of competition. Coaches should modify drills within training to allow players to be exposed to their maximal velocity or incorporate linear based running over a distance that allows players to attain these maximal velocities within the training environment.

Practical Applications

- Exposure of players to maximal velocity running should be mainstream practice in elite sport in order to adequately prepare players for maximal velocity situations during match-play

- Coaches should allow for situations within training where players can achieve high percentages of maximal velocity as these situations offer a potential protective effect against injury.

- Players who produce ≥ 95% of their maximal velocity are at reduced injury risk compared to players who produced lower relative maximal velocities.

- Players with higher chronic training loads were able to achieve greater exposures to maximal velocity running at reduced risk. Therefore, physically hard but well planned training seems an effective approach of preparing players for maximal velocity components of training.

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452 **Figure 1.** Association between total weekly maximal velocity exposures and likelihood of injury.

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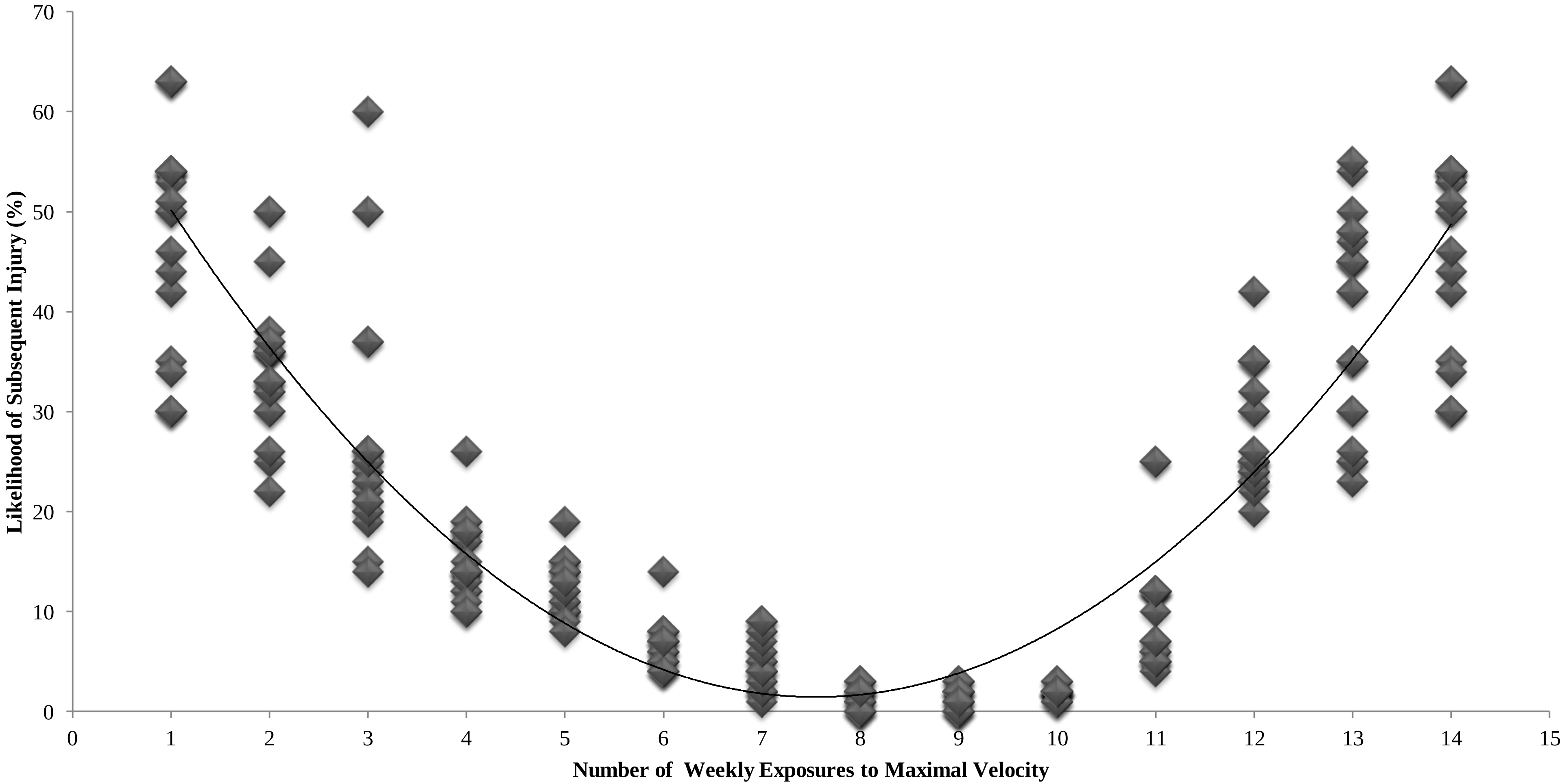

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Table 1. Relative maximal velocity as a risk factor for injury in elite Gaelic football players. Data presented as OR (95% CI) when compared to a reference group.

External Load Calculation	In-Season			
	OR	95% Confidence Interval		*p*-Value
	Exp (B)	Lower	Upper	
Relative Maximal Velocity (%)				
≤ 85 % (Reference)	1.00			
Between 85 to 90 %	0.72	0.75	2.21	0.336
Between 90 to 95 %	0.22	0.10	1.22	0.026
≥ 95 %	0.12	0.01	0.92	0.001

Table 2. Combined effect of chronic (4 week) training load history and exposure to maximal velocity events as a risk factor for injury in elite Gaelic football players. Data presented as OR (95% CI) when compared to a reference group.

Internal Training Load	In-Season			
	OR Exp (B)	95% Confidence Interval Lower	95% Confidence Interval Upper	*p*-Value
Maximal Velocity Exposures Low Chronic Training Load (≤ 4750 AU)				
≤ 5 (Reference)	1.00			
Between 5 to 10 exposures	1.02	0.83	1.25	0.636
Between 10 to 15 exposures	0.99	0.28	1.22	0.787
≥ 15 exposures	3.38	1.60	6.75	0.001
Maximal Velocity Exposures High Chronic Training Load (≥ 4750 AU)				
≤ 5 (Reference)	1.00			
Between 5 to 10 exposures	0.72	0.75	2.21	0.236
Between 10 to 15 exposures	0.22	0.10	1.22	0.026
≥ 15 exposures	1.03	0.70	2.62	0.433

Table 3. Combined effect of chronic (4 week) training load history and exposure to different maximal velocity distances as a risk factor for injury in elite Gaelic football players. Data presented as OR (95% CI) when compared to a reference group.

Internal Training Load	In-Season			
	OR	95% Confidence Interval		*p*-Value
	Exp (B)	Lower	Upper	
Total weekly distance covered at maximal velocity (m)				
Low Chronic Training Load (≤ 4750 AU)				
< 60 m	1.00			
Between 60 to 90 m	1.52	1.81	3.90	0.005
Between 90 to 120 m	1.72	0.05	1.11	0.016
Between 120 to 150 m	3.12	1.11	4.99	0.011
High Chronic Training Load (≥ 4750 AU)				
< 60 m	1.00			
Between 60 to 90 m	0.12	0.06	1.16	0.035
Between 90 to 120 m	0.23	0.10	1.33	0.055
Between 120 to 150 m	0.26	0.09	1.45	0.056