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

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19
20 **Running Title:** Exposure to maximal velocity protects against injury.

21
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31 **ABSTRACT**

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

36

37 **Design:** Prospective cohort design

38

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

48

49 **Results:** Players who produced over 95% maximal velocity on at least one occasion within
50 training environments had lower risk of injury compared to the reference group of 85%
51 maximal velocity on at least one occasion (OR: 0.12, $p = 0.001$). Higher chronic training
52 loads (≥ 4750 AU) allowed players to tolerate increased distances (between 90 to 120 m) and
53 exposures to maximal velocity (between 10 to 15 exposures), with these exposures having a
54 protective effect compared to lower exposures (OR: 0.22 $p = 0.026$) and distance (OR =
55 0.23, $p = 0.055$).

56

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

61

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

63 INTRODUCTION

64 Training load has been reported as a modifiable risk factor for subsequent injury ¹.
65 Several studies have investigated the influence of training workload and injury risk in team
66 sports. In professional rugby union, players ¹ higher 1-week (> 1245 AU) and 4-week
67 cumulative loads (> 8651 AU) were associated with a greater risk of injury. Furthermore,
68 Rogalski et al. ² observed that larger 1-weekly (>1750 arbitrary units, OR= 2.44–3.38), 2-
69 weekly (>4000 arbitrary units, OR= 4.74) and previous to current week changes in load
70 (>1250 arbitrary units, OR = 2.58) were significantly related to greater injury risk throughout
71 the in-season phase in elite Australian rules football players.

72
73 The ability to produce high speeds is considered an important quality for
74 performance, with athletes shown to achieve 85-94% of maximal velocity during team sport
75 match-play ³. Well-developed high-speed running ability and maximal velocity are required
76 of players during competition in order to beat opposition players to possession and gain an
77 advantage in attacking and defensive situations ^{4,5}. In order to optimally prepare players for
78 these maximal velocity and high speed elements of match play, players require regular
79 exposure to periods of high-speed running during training environments ⁶ in order to attain
80 high percentages of maximal velocity. Recent evidence suggests that lower limb injuries are
81 associated with excessive high-speed running exposure ^{7,8}. Within elite rugby league and
82 Australian football cohorts, players who performed greater amounts of very high-speed
83 running within training sessions were 2.7 and 3.7 times more likely to sustain a non-contact,
84 soft tissue injury than players who performed less very-high speed running ^{8,9}. However,
85 these studies failed to assess the potential impact that chronic training load could have on
86 reducing the injury risk in these players. Currently there is a lack of understanding of the
87 potential benefits of maximal velocity exposures and also the minimum dose required to
88 provide protection against injuries.

89
90 Recent evidence suggests that high chronic training loads can offer a protective
91 stimulus for team sport athletes ^{10,11}. Australian rules football players with higher 1 week
92 training loads (> 3519 AU) were at reduced risk of injury (OR = 0.199) compared to players
93 exposed to lower training loads (< 3518 AU) ¹². Additionally Cross et al. ¹ have reported a U-
94 shaped curve for training load and injury risk in elite rugby union players with low and high
95 training loads increasing injury risk, and intermediate loads reducing injury risk. High aerobic

96 fitness has been reported to offer a protective effect against subsequent lower limb injury for
97 team sport players⁶. Higher training loads may be needed to provide the appropriate stimulus
98 for aerobic fitness improvements⁶ with lower training loads potentially placing players at
99 increased risk due to a lack of exposure to the physical stimulus required for competitive play
100⁶.

101

102 Although greater amounts of high-speed running have been associated with injury
103 risk, there is evidence that players are often required to perform maximal efforts over short to
104 moderate distances during competition and training^{3, 8, 13, 14, 15}. Training for team sport
105 ultimately requires a balance between appropriately prescribed training loads to develop the
106 required physical qualities to compete while also allowing the appropriate recovery between
107 sessions and match-play to minimise injury risk for players. Given the need for players to
108 perform maximal efforts during match-play, exposure of players to these maximal efforts
109 during training may offer a “vaccine” against soft-tissue injury⁶. However, the inter-
110 relationship among these training variables and potential injury risk is poorly understood.
111 Therefore the aim of the current investigation was to examine exposure to maximal velocity
112 events as a potential modifiable risk factor for injury within Gaelic football. Additionally
113 with higher chronic training loads offering a protective effect from injury in other sports,
114 there is a need to investigate the interaction of chronic training loads, maximal velocity
115 exposure, and injury risk within Gaelic football. Accordingly, we explored the relationship
116 between training load, the number of maximal velocity exposures during training and match-
117 play, the distance covered at maximal velocity and injury risk in elite Gaelic football players.

118

119 **METHODS**

120

121 The current investigation was a prospective cohort study of elite Gaelic football
122 players competing at the highest level of competition in Gaelic football (National League
123 Division 1 and All-Ireland Championship). Data were collected for 37 players (Mean \pm SD,
124 age: 24 ± 3 years; height: 179 ± 5 cm; mass: 79 ± 7 kg) over one season. The study was
125 approved by the local institute’s research ethics committee and written informed consent was
126 obtained from each participant.

127

128 The intensity of all competitive match-play and training pitch based sessions
129 (including recovery and rehabilitation sessions) were estimated using the modified Borg CR-

130 10 rate of perceived exertion (RPE) scale, with ratings obtained from each individual player
131 within 30 minutes of completing the match or training session ¹⁶. Each player was asked to
132 report their RPE for each session confidentially without knowledge of other players' ratings.
133 Each individual player's session RPE in arbitrary units (AU) was then derived by multiplying
134 RPE and session duration (min) ¹⁶. Session-RPE (sRPE) has previously been shown to be a
135 valid method for estimating exercise intensity ¹⁷. sRPE was then used to calculate 4-week
136 chronic workload (i.e., 4-week average acute workload) ^{18,19}.

137

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

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

166

167 All GPS and lower limb soft tissue injuries were classified into acute 1-weekly blocks
168 and chronic 4-weekly blocks using a bespoke database. Data were collected from 95 pitch
169 based training sessions from November through September. Each player participated in 2 to 3
170 pitch based training sessions depending on the week of the season. The pitch based training
171 sessions were supplemented by 2 gym based, strength training sessions. The duration of the
172 pitch based training sessions was typically between 60 and 130 minutes depending on session
173 goals. All injuries that prevented a player from taking full part in all training and match-play
174 activities typically planned for that day, and prevented participation for a period greater than
175 24 h were recorded. The current definition of injury mirrors that employed by Brooks et al. ²¹
176 and conforms to the consensus time loss injury definitions proposed for team sport athletes
177 ^{22,23}. All injuries were further classified as being low severity (1–3 missed training sessions);
178 moderate severity (player was unavailable for 1–2 weeks); or high severity (player missed 3
179 or more weeks). Injuries were also categorised for injury type (description), body site (injury
180 location) and mechanism ².

181 SPSS Version 22.0 (IBM Corporation, New York, USA) and R (version 2.12.1)
182 software were used to analyze the data. Descriptive statistics were expressed as means \pm SD
183 and 95% confidence intervals of maximal velocity running loads and the number of maximal
184 velocity exposures during the season. Injury incidence was calculated by dividing the total
185 number of injuries by the total number of training hours and match hours. These hours were
186 then expressed as a rate per 1,000 hours. The 95% confidence intervals (CIs) were calculated
187 using the Poisson distribution, and the level of significance was set at $p \leq 0.05$. Maximal
188 velocity exposure values and injury data (injury vs. no injury) were then modelled using a
189 logistic regression analysis with adjustment for intra-player cluster effects. Data were initially
190 split into quartiles (four even groups), with the lowest training load range used as the
191 reference group. This was completed for relative maximal velocity, weekly maximal velocity
192 distance and the total number of maximal velocity exposures. Additionally, to better
193 understand the impact of previous chronic training load on maximal velocity running,
194 training data was divided into low (≤ 4750 AU) and high (≥ 4750 AU) chronic training load
195 groups using a dichotomous median split. Maximal velocity distance, maximal velocity
196 exposures, and injury data were summarised at the completion of each week. Acute and

197 chronic training load were calculated as described previously¹⁹. Previous training load
198 history was then associated with players' tolerance to maximal velocity distance, maximal
199 velocity exposures and injuries sustained in the subsequent week.. Players who sustained an
200 injury were removed from analysis until they were medically cleared to return to full training.
201 Odds ratios (OR) were calculated to determine the injury risk at a given relative percentage of
202 maximal velocity, chronic training load, number of maximal velocity exposures, and distance
203 covered (m) at maximal velocity. When an OR was greater than 1, an increased risk of injury
204 was reported (i.e., OR = 1.50 is indicative of a 50% increased risk) and vice versa. Based on a
205 total of 91 injuries from 3,515 player-sessions, the calculated statistical power to establish the
206 relationship between running loads and soft-tissue injuries was 85%.

207

208 **RESULTS**

209 In total, 91 time-loss injuries were reported across the season (36 training injuries and
210 55 match injuries). A rate of 2.4 injuries per player was observed. Overall, match injury
211 incidence was 45.3/1000 hours (95% CI: 41.9-53.8) with a training injury incidence of
212 6.9/1000 hours (95% CI: 5.8-7.8). The total match and training volumes reported during the
213 season were 1,210 hours and 5,975 hours respectively.

214

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

223

224 The average session training load was 695 ± 136 AU during the study period, with an
225 average acute weekly training load of 3475 ± 596 AU. When previous training load was
226 considered, players with a higher chronic training load (≥ 4750 AU) were able to tolerate
227 increased exposures to maximal velocity (between 10 to 15 exposures) events, with these
228 having a protective effect compared to lower exposures (OR: 0.22 95% CI 0.10-1.22 $p =$
229 0.026). Players with a lower chronic training load (≤ 4750 AU) were at increased injury risk

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

232

233 The average seasonal 1-weekly running distance covered at maximal velocity was 170
234 ± 69 m. Players who exerted higher chronic training loads (≥ 4750 AU) were at significantly
235 reduced risk of injury when they covered 1-weekly maximal velocity distances of 90 to 120
236 m compared to the reference group of < 60 m (OR = 0.23, 95% CI 0.10–1.33, $p = 0.055$).
237 Conversely, players who had exerted low chronic training loads (≤ 4750 AU) and covered the
238 same distance of 90 to 120 -m were at significantly higher risk of injury compared to the
239 reference group of < 60 m (OR = 1.72, 95% CI 1.05–2.47, $p = 0.016$) (Table 3).

240

241 **DISCUSSION**

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

257

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

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

273

274 We found that players with higher chronic loads (≥ 4750 AU) experienced increased
275 exposures to maximal velocity, with this increase in exposure offering a protective effect
276 against injury. This might be explained by these players being exposed to previous training
277 load that improved their ability to tolerate subsequent load, ultimately reducing their risk of
278 injury. In contrast, players with low chronic loads were at greater risk of injury when
279 exposed to the same number of maximal velocity exposures, perhaps reflecting the
280 consequences of inadequate exposure to a sufficient workload over the previous period. Our
281 results are in line with previous investigations from rugby league that have suggested that
282 higher chronic loads protect against injury¹⁰. Therefore coaches should consider that the
283 prescription of training that emphasises reductions in training load may actually increase
284 athlete's susceptibility to injury due to inadequate chronic loads and fitness levels^{6, 24}.
285 However, coaches need to be aware that high chronic workloads, combined with large spikes
286 in acute workload have previously demonstrated the greatest risk of injury in team sport
287 players¹⁰; this would appear to be an important consideration when increasing training loads
288 in order to return players to competitive play.²⁵ Coaches should be aware that although
289 exposure to maximal velocity has a protective effect, players with higher chronic training
290 loads are better prepared to tolerate subsequent maximal velocity load.

291

292 The current data has shown that depending on previous chronic training load status
293 players can tolerate more intense periods of training. Players with higher chronic training
294 loads were able to cover increased weekly distances (120 to 150 m) at maximal velocity with
295 lower subsequent injury risk (OR: 0.26). Interestingly players with lower chronic loads were
296 at increased risk of subsequent injury (OR: 3.12) at the same weekly running load (120 to 150
297 m). The current data provides information that advocates players covering moderate distance

298 at their individual maximal velocity. Coaches must be aware that players need to have the
299 necessary physical qualities in order to tolerate the exposures to maximal running volumes ⁶
300 as highlighted by the difference between low and high chronic load groupings. This is
301 supported by previous observations ⁸ which found that players who covered more distance at
302 very-high speed (> 9 m) suffered less time loss from injury when compared to those who
303 covered less than 9 m. Finally, those players who covered greater absolute distances at high-
304 speeds (> 190 m) missed fewer matches than players who covered less distance at the same
305 thresholds ⁸.

306

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

320

321 **CONCLUSION**

322

323 In conclusion when maximal velocity exposures were considered independently of
324 training load history a U-shaped curve was shown for number of exposures and subsequent
325 injury risk. Our data suggests that players who produce $\geq 95\%$ of their maximal velocity were
326 at reduced injury risk compared to players who produced lower relative maximal velocities.
327 Coaches should expose players to high percentages of maximal velocity within training
328 situations as this offers a potential “vaccine” against subsequent soft tissue injury. Players
329 with higher chronic training loads (≥ 4750 AU) were able to cover increased weekly
330 distances (120 to 150 m) at maximal velocity with lower subsequent injury risk, while players
331 with lower chronic loads were at increased risk of subsequent injury at the same weekly

332 running load. Coaches should be aware that players need to partake in hard but well planned
333 training to be protected from subsequent injury. Finally, our findings suggest that exposure of
334 players to maximal velocity running should be mainstream practice in elite sport in order to
335 adequately prepare players for the demands of competition. Coaches should modify drills
336 within training to allow players to be exposed to their maximal velocity or incorporate linear
337 based running over a distance that allows players to attain these maximal velocities within the
338 training environment.

339

340 **Practical Applications**

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

344

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

348

349

350 • Players who produce $\geq 95\%$ of their maximal velocity are at reduced injury risk
351 compared to players who produced lower relative maximal velocities.

352

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

357

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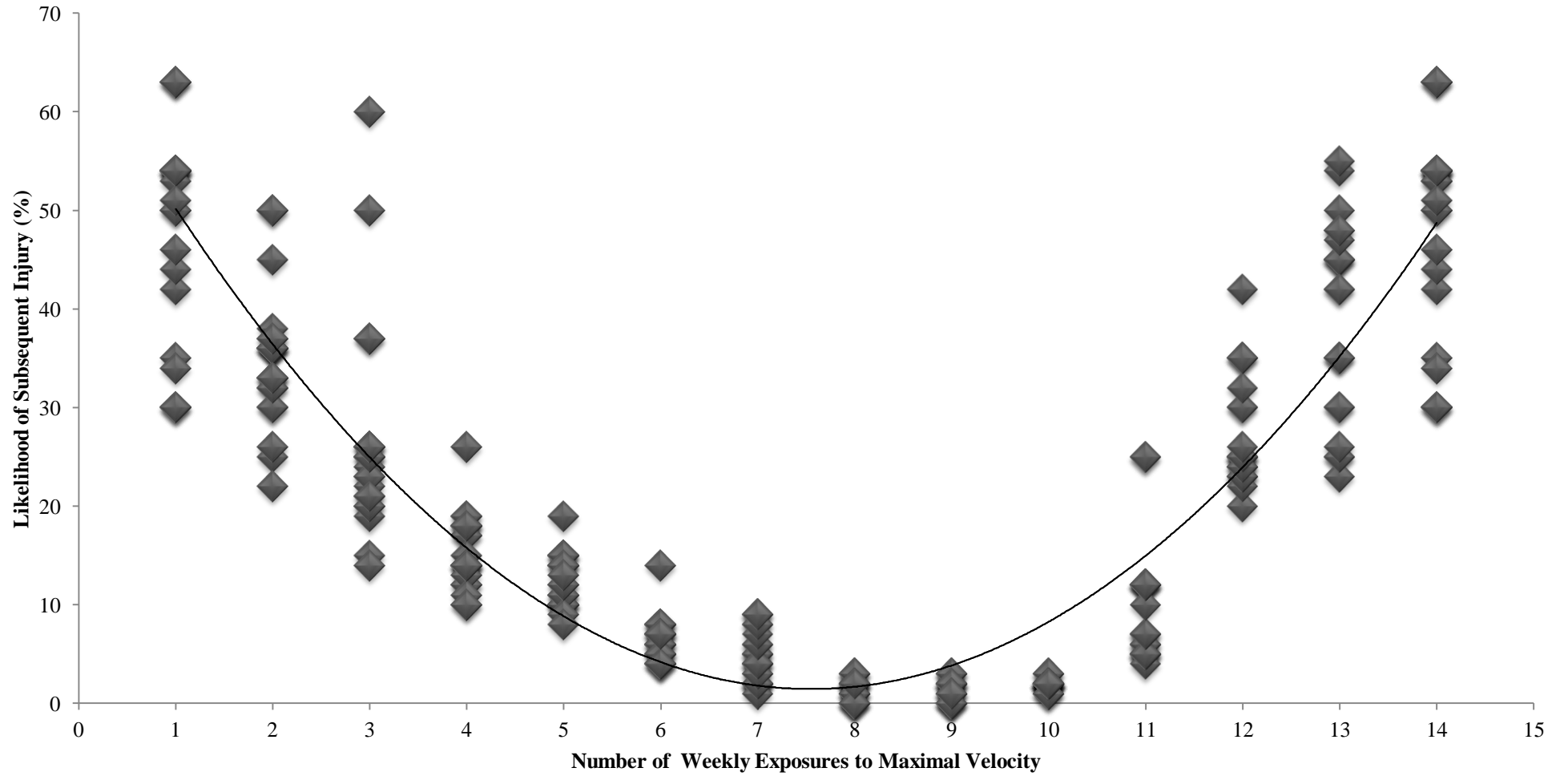
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452 **Figure 1.** Association between total weekly maximal velocity exposures and likelihood of injury.

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457 **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
 458 reference group.
 459

External Load Calculation	In-Season			p-Value
	OR Exp (B)	95% Confidence Interval		
		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

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477 **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
 478 Gaelic football players. Data presented as OR (95% CI) when compared to a reference group.
 479

Internal Training Load	In-Season			p-Value
	OR Exp (B)	95% Confidence Interval		
		Lower	Upper	
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

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488 **Table 3.** Combined effect of chronic (4 week) training load history and exposure to different maximal velocity distances as a risk factor for
 489 injury in elite Gaelic football players. Data presented as OR (95% CI) when compared to a reference group.
 490

Internal Training Load	In-Season			p-Value
	OR Exp (B)	95% Confidence Interval		
		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

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