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1 **Title:** Can the workload-injury relationship be moderated by improved strength, speed and repeated-
2 sprint qualities?

3 **Manuscript Type:** Original Investigation

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19

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33 **ABSTRACT**

34 **Objectives:** The aim of this study was to investigate potential moderators (i.e. lower body strength,
35 repeated-sprint ability [RSA] and maximal velocity) of injury risk within a team-sport cohort.

36 **Design:** Observational Cohort Study

37 **Methods:** Forty male amateur hurling players (age: 26.2 ± 4.4 yr, height: 184.2 ± 7.1 cm, mass: $82.6 \pm$
38 4.7 kg) were recruited. During a two-year period, workload (session RPE x duration), injury and
39 physical qualities were assessed. Specific physical qualities assessed were a three-repetition maximum
40 Trapbar deadlift, 6 x 35-m repeated-sprint (RSA) and 5-, 10- and 20-m sprint time. All derived workload
41 and physical quality measures were modelled against injury data using regression analysis. Odds ratios
42 (OR) were reported against a reference group.

43 **Results:** Moderate weekly loads between ≥ 1400 AU and ≤ 1900 AU were protective against injury
44 during both the pre-season (OR: 0.44, 95%CI: 0.18 – 0.66) and in-season periods (OR: 0.59, 95% CI:
45 0.37 – 0.82) compared to a low load reference group (≤ 1200 AU). When strength was considered as a
46 moderator of injury risk, stronger athletes were better able to tolerate the given workload at a reduced
47 risk. Stronger athletes were also better able to tolerate larger week-to-week changes (>550 AU to 1000
48 AU) in workload than weaker athletes (OR = 2.54 – 4.52). Athletes who were slower over 5-m (OR:
49 3.11, 95% CI: 2.33 – 3.87), 10-m (OR: 3.45, 95% CI: 2.11 – 4.13) and 20-m (OR: 3.12, 95% CI: 2.11
50 – 4.13) were at increased risk of injury compared to faster athletes. When repeated-sprint total time
51 (RSA_t) was considered as a moderator of injury risk at a given workload (≥ 1750 AU), athletes with
52 better RSA_t were at reduced risk compared to those with poor RSA_t (OR: 5.55, 95%: 3.98 – 7.94).

53 **Conclusions:** These findings demonstrate that well-developed lower-body strength, RSA and speed are
54 associated with better tolerance to higher workloads and reduced risk of injury in team-sport athletes.

55

56 **Key Words:** Strength, Speed, Repeated-Sprint Ability, Odds-Risk, Injury Prevention

57

58 INTRODUCTION

59 The process of planning appropriate workloads is a cross-discipline effort involving
60 management, strength and conditioning and medical staff encompassing an ever evolving and holistic
61 process ¹. Adequate workloads are required to improve player's physical and performance qualities ^{2,3}
62 however, there is a balance to be considered between improving fitness and increasing player fatigue ⁴.
63 The evolving nature of team based sports has resulted in an increased interest in monitoring player
64 activities quantitatively on a daily and weekly basis ⁵. As such the prescription of appropriate training
65 loads requires careful consideration by all stakeholders to best maximise performance levels while
66 minimising the negative (injury) effects of the prescribed load ⁵. While several studies have
67 documented the relationship between specific elements of training load and injury ^{6,7} in team sport
68 players, very few have investigated potential mediators and moderators of injury risk within these
69 cohorts.

70 The process leading to a specific injury occurrence is multifactorial, and thus attributing
71 injuries to single risk factors is a gross simplification of the injury process ^{8,9}. Therefore, the
72 interpretation of the workload-injury relationship can never be completed in isolation ¹⁰. Instead, it is
73 important for practitioners to understand the specific mechanisms such as workload spikes, physical
74 qualities, playing experience, and previous injury that may increase (or decrease) the likelihood of
75 injury ^{10,11}. Furthermore, it is important that the characteristics that make athletes more robust or more
76 susceptible to injury at any given workload are better understood. To date, no study has investigated
77 which factors potentially *mediate* or *moderate* the workload-injury relationship ¹⁰. Specifically, it is
78 known in rugby league that rapid increases in running workloads, indicated by a high acute:chronic
79 workload ratio, *mediated* the risk for non-contact injuries ¹². However, in Gaelic football and soccer
80 players, high aerobic fitness *moderated* the risk for non-contact injuries ^{2,11}.

81 Recently, workload-injury investigations have examined absolute weekly workloads (1-4
82 weekly) and acute workloads relative to chronic workloads (acute:chronic workload) ^{2,6}. Previously
83 higher workloads have been reported to have either positive or negative influences on injury risk ^{7,11}.
84 Specifically, compared with players who had a low chronic workload, players with a high chronic
85 workload were more resistant to injury with moderate-low through moderate-high (0.85–1.35)
86 acute:chronic workload ratios and less resistant to injury when subjected to 'spikes' in acute workload
87 ¹². In addition, higher chronic workloads combined with well-developed aerobic fitness can moderate
88 subsequent injury risk ^{3,11}. Indeed, Gaelic football players with higher chronic loads were able to
89 complete maximal velocity running exposures at lower risk than players with lower chronic loads ¹¹.
90 High training loads, designed to develop physical qualities, are thought to be critical to prepare players
91 for competition. Ultimately there is the need to understand which physical qualities best protect players
92 during these periods of increased load ¹. To date, speed, lower-body strength, and repeated-sprint ability

93 (RSA) have not been investigated as potential moderators of injury risk ¹⁰. There is a need for
94 practitioners to understand the mediators and moderators of injury risk within team sport athletes. At
95 present, very few studies ^{3,6} have analysed multiple physical qualities and determined how these
96 qualities subsequently impact the workload-injury relationship. As such, the purpose of the current
97 investigation was to examine the relationship between training load, physical qualities and injury in
98 team sport players.

99

100 **METHODS**

101 Forty amateur male hurling players (age = 26.2 ± 4.4 years, height = 182.2 ± 7.1 cm, mass =
102 81.3 ± 3.7 kg) with a median of 5 years (range 1-12 years) playing experience from a single team were
103 recruited for this study. The human research ethics committee of the local institution approved the study
104 and participants gave informed written consent prior to the observational period.

105 All time-loss injuries were recorded using a bespoke database for data collection. All injuries
106 that prevented a player from taking full part in all training and match-play activities typically planned
107 for that day, and prevented participation for a period greater than 24 h were recorded. The current
108 definition mirrors that employed by Brooks et al. ¹³ and conforms to the consensus time-loss injury
109 definitions proposed for team sport athletes ^{14,15}. All injuries were classified as being low severity (1–3
110 missed training sessions); moderate severity (player was unavailable for 1–2 weeks); or high severity
111 (player missed 3 or more weeks). Injuries were also categorised for injury type (description), body site
112 (injury location) and mechanism ¹⁶.

113 Data were collected from 241 pitch and gym based training sessions across a two-year period.
114 Each player participated in 2 to 3 pitch based training sessions depending on the week of the season.
115 During the pre-season, training sessions typically had elements of position-specific fitness work in
116 addition to technical and tactical elements. As the season progressed there was a focus towards
117 increased technical and tactical work. This resulted in a reduction of fitness-specific elements. The pitch
118 based training sessions were supplemented by 1-2 gym-based, strength training sessions per week
119 depending on the phase of the season. The duration of the pitch based training sessions was typically
120 between 60 and 110 minutes depending on session goals. The typical gym-based session was 60-80
121 minutes with both upper and lower body exercises completed within the program.

122 The intensity of all training sessions (including rehabilitation sessions) and match-play were
123 estimated using the modified Borg CR-10 rate of perceived exertion (RPE) scale, with ratings obtained
124 from each individual player immediately after the completion of each training session and match ^{2,3}.
125 Each player had the scale explained to them before the start of the season and players were asked to
126 report their RPE for each session confidentially without knowledge of other players' ratings ¹⁶. Session-

127 RPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration
128 (min). Session-RPE (s-RPE) has previously been shown to be a valid method for estimating exercise
129 intensity¹⁷. The collection of s-RPE also allowed for the quantification of the following training load
130 measures, 1 week rolling through 4 week rolling load, acute:chronic workload ratio (ACWR; 1-week:4-
131 week) and absolute change in workload (the previous to current week)^{2,8}. A weekly cycle of training
132 load was defined from Sunday to Sunday, this allowed for match-play events to be calculated within a
133 week of training load. A one-week acute load comparison to four-week chronic load period is suited to
134 Gaelic sports such as hurling given that most training programs are designed by coaches around 4-week
135 cycles during the season due to limited match-play events during the seasonal period.

136 The physical qualities of players were assessed by conditioning staff during each phase of each
137 season across a two-day testing period with 24-hours between testing days. Specifically, during the
138 observational period the conditioning staff assessed maximal lower body strength (3 RM Trapbar
139 deadlift), maximal linear speed across 5-, 10-, and 20-m and repeated-sprint ability (RSA). On day one
140 of testing maximum lower body strength was assessed using a 3-repetition maximum (RM) Trapbar
141 deadlift exercise performed using a free-weight barbell. After warming up with progressively heavier
142 loads, the athlete attempted their self-selected 3RM. The intraclass correlation coefficient (ICC) for test
143 retest reliability and typical error of measurement (TEM) for the 3RM Trapbar deadlift were 0.93 and
144 2.3%, respectively. The final weight lifted was then referenced to players' body mass to provide relative
145 lower body strength. After a one-hour recovery period, players linear sprint speed was assessed using a
146 5-, 10- and 20-m sprint. Players sprinted from a standing start. Players were instructed to run as quickly
147 as possible along the 20-m distance. Speed was measured to the nearest 0.01 second, with the fastest
148 value obtained from 2 trials used as the speed score. For the 5-, 10- and 20-m sprint tests, the ICC for
149 test-retest reliability were 0.95, 0.96 and 0.97, respectively, and the TEM were 1.8%, 1.6% and 1.2%,
150 respectively. On day two of the assessment, a RSA test was conducted using six repeated 35-m shuttles
151 with 10 seconds of passive recovery between efforts¹⁸. Players sprinted from a standing start and were
152 instructed to sprint as fast as they could for each repeated effort with total sprint time (RSA_t; s) recorded.
153 The ICC for test-retest reliability was 0.95, for RSA_t and TEM was 1.2%. Both linear running tests were
154 monitored with a photocell timing gate system (Witty, Mircrogate, Bolzano, Italy).

155 Data were analysed in SPSS Version 22.0 (IBM Corporation, New York, USA). A chi-squared
156 analysis was used to compare the frequency of injuries at different workloads and physical qualities
157 across the seasonal phases. Based on the total injuries and sessions completed the calculated statistical
158 power to establish the association between workload, physical qualities and soft-tissue injury was 83%.
159 Weekly load exposure values, physical qualities and all injury data (injury vs. no injury) including
160 subsequent week injuries, were then modelled using a second order polynomial regression. Data were
161 divided into quartile ranges, with a given workload and physical quality range being used as a reference
162 analysis grouping. Odds ratios (OR) were calculated to determine the injury risk at a given cumulative

163 workload (1, 2, 3 and 4-weekly cumulative), ACWR and for absolute change in workload (the previous
164 to current week). Correlation coefficients between the training load measures, alongside variance
165 inflation factors (VIF), were used to detect multicollinearity between the predictor variables. A VIF of
166 ≥ 10 was deemed indicative of substantial multicollinearity¹⁹. Within our model, all load measures
167 provided a VIF of ≤ 10 therefore providing acceptable levels of multicollinearity. When an OR was
168 greater than 1, an increased risk of injury was reported (i.e., OR = 1.50 is indicative of a 50% increased
169 risk) and vice versa.

170 **RESULTS**

171 In total, 93 time-loss injuries were reported across the two-seasons. Overall the most common
172 site of injury was the thigh (35%), the knee (11%) and the ankle (17%) with pelvis/groin injuries
173 accounting for 14% of overall injuries. The performance profile of the investigated cohort are shown in
174 Supplementary Table 1. The typical one weekly through to four weekly loads and ACWR as potential
175 risk factors associated within injury are shown in Supplementary Figure 1 and Supplementary Table 2
176 respectively. Moderate weekly loads between ≥ 1400 AU and ≤ 1900 AU were shown to protect players
177 during both the pre-season (OR: 0.44, 95%CI: 0.18 – 0.66) and in-season periods (OR: 0.59, 95% CI:
178 0.37 – 0.82) compared to a low weekly load group of ≤ 1200 AU. There were consistent trends for
179 moderate loads to offer reduced odds of injury for 2-weekly, 3-weekly and 4-weekly loads across both
180 the pre-season and in-season phases. Large absolute weekly changes in load (≥ 1000 AU) were shown
181 to increase the odds of injury compared to smaller weekly changes in load during the pre-season (OR:
182 5.58, 95% CI: 3.19 – 7.32) and in-season (OR: 4.98, 95% CI: 2.33 – 5.36) phases. An ACWR between
183 0.90 and 1.30 was shown to offer protective effects, with the ratio explaining 60% of the variance
184 associated with likelihood of subsequent injury (Supplementary Figure 1). When relative strength was
185 considered independent of other factors, players who had higher relative strength qualities were at
186 reduced risk of injury compared to their lower relative strength counterparts (Figure 1). When strength
187 was assessed as a moderator on injury risk at a given weekly workload (≥ 1750 AU), stronger athletes
188 were better able to tolerate the given workload at a reduced risk (Table 1). Stronger athletes were also
189 better able to tolerate larger week to week changes (>550 AU to 1000 AU) in workload than weaker
190 athletes (OR = 2.54 – 4.52). When a given ACWR and strength were considered, stronger athletes were
191 shown to tolerate spikes in workload better than weaker athletes (OR: 1.33 – 5.10). Faster athletes over
192 5-, 10-, and 20-m had lower injury risk than slower athletes (Figure 1). When speed qualities were
193 considered as a moderator at a given weekly workload (≥ 1750 AU), athletes who were slower over 5-
194 m (OR: 3.11, 95% CI: 2.33 – 3.87), 10-m (OR: 3.45, 95% CI: 2.11 – 4.13) and 20-m (OR: 3.12, 95%
195 CI: 2.11 – 4.13) were at increased risk compared to the faster athlete reference group. Additionally,
196 slower 5-m (OR: 3.98, 95%CI: 2.34 – 4.55), 10-m (OR: 2.78, 95%CI: 1.32 – 3.14) and 20-m (OR: 4.55,
197 95%CI: 2.12 – 4.98) athletes had increased injury risk when the weekly ACWR was ≥ 1.25 (Table 2).
198 Athletes with better RSA_t had lower risk than players with slower RSA_t, when considered independently

199 of all other variables (Figure 1). When RSA_t was considered as a moderator of injury risk at a given
200 workload (≥ 1750 AU), athletes with better RSA_t had lower risk than players with slower RSA_t (OR:
201 5.55, 95%: 3.98 – 7.94). Athletes with slower RSA had higher odds of injury and were unable to tolerate
202 larger week to week changes (>550 AU to 1000 AU) in workload than athletes with better RSA_t (OR =
203 2.54 – 6.52), with similar trends reported for a given ACWR (Supplementary Table 2).

204 **DISCUSSION**

205 This study investigated the association between measures of training load, physical qualities
206 and injury risk in team sport (i.e. hurling) players. Our data highlights that moderate weekly loading
207 offers a protective effect for team sport athletes. In agreement with previous literature^{2,8} we have shown
208 that the ACWR has an association with injury risk with the ratio explaining 60% of the variance in
209 injury risk within the current cohort. Furthermore, we have identified greater relative lower body
210 strength, faster speed and repeated-sprint ability as potential moderators of subsequent injury risk.
211 Specifically, when considered both independently and at specific absolute workloads, relatively
212 stronger athletes were at reduced risk of injury compared to their weaker counterparts. Similarly, we
213 found that faster athletes over 5-m, 10-m and 20-m were at lower risk of injury than their slower
214 counterparts. Finally, our data highlights the need to consider the repeated-sprint abilities of team sport
215 athletes given the observed relationship between faster RSA_t and reduced injury risk in this cohort.

216 Our findings agree with the previously observed association between weekly training loads and
217 injury risk in team sport athletes^{2,3}. Interestingly, we consistently observed that moderate weekly loads
218 offered protective effects for athletes across both the pre-season and in-season phases. In agreement
219 with previous studies^{7,16}, higher weekly workloads resulted in increased risk of injury for players.
220 Players who exerted moderate weekly loads of between ≥ 1400 AU to ≤ 1900 AU had lower injury risk
221 than players who exerted lower loads, with this finding observed during both the pre-season (OR: 0.44,
222 95%CI: 0.18 – 0.66) and in-season periods (OR: 0.59, 95% CI: 0.37 – 0.82). In line with previous
223 literature on the workload-injury association^{3,10}, larger absolute weekly changes in load (≥ 1000 AU)
224 were shown to increase the odds of injury compared to smaller weekly changes in load during both the
225 pre-season (OR: 5.58, 95% CI: 3.19 – 7.32) and in-season (OR: 4.98, 95% CI: 2.33 – 5.36) phases.
226 These results highlight the need to appropriately load players from week to week to ensure improved
227 physical capacities which in turn have been shown to protect against injury within team sport athletes
228^{3,10}.

229 Interestingly we observed that moderate loading patterns protected players from injury both in
230 pre-season and in-season. This finding is in contrast to previous findings where higher workloads have
231 been associated with lower injury risk^{11,12}. One potential explanation for this finding may be directly
232 related to training time with players only training two to three times per week, with it difficult for
233 players to attain higher loads due to limited training time. Ultimately, coaches and medical staff need

234 to work holistically to effectively improve physical capacities while reducing the injury risk of players
235 ^{1,8}, particularly during the pre-season phase where within many team sports there is a specific focus on
236 improving the fitness levels of players which often involves higher training loads. While moderate loads
237 and U-shaped curves (i.e. lower and higher loading patterns increasing risk of injury) have been
238 previously noted within the literature¹¹ there is a fine balance to be struck by coaches. Ultimately
239 coaches will need to maintain adequate chronic loads while manipulating acute loads to ensure
240 improved fitness and reduced injury risk ⁸. This can be achieved by maintaining an ACWR of between
241 0.90 and 1.30. Interestingly, in the current investigation, the ACWR explained 60% of the variance
242 associated with likelihood of subsequent injury compared to 52% in previous literature ⁸. However,
243 practitioners need to be aware that several limitations have been suggested when using a s-RPE derived
244 ACWR. Firstly, although sRPE has been shown to provide a valid indication of internal training load,
245 it may underestimate the average intensity of resistance exercise ²⁷, with fatigue potentially confounding
246 the relationship between RPE and relative intensity ²⁸. Although strength training sessions in the current
247 study only comprised a small proportion of total training load, it is possible that the total training load
248 experienced by players may be slightly underestimated due to the mismatch between perceived and
249 actual resistance training intensity. Secondly, s-RPE is unlikely to be sensitive to the subtle changes in
250 high-speed running movements of match-play and training which have been shown to be important
251 within the injury-workload paradigm¹¹. Therefore, a coach's injury prevention and monitoring
252 philosophy should not be limited to the monitoring of a single training load variable. As such
253 understanding an athlete's physical qualities in addition to their sporting and individual needs, is
254 fundamental to ensure athletes are healthy across a competitive season. Furthermore, the ACWR-injury
255 relationship will ultimately differ between sporting codes and cohorts.

256 Our data highlights for the first time that relative strength can moderate injury risk for team
257 sport athletes. Specifically, stronger athletes were better equipped to tolerate larger week to week
258 changes in workload along with higher absolute workloads. Interestingly, athletes with a higher relative
259 strength were also shown to tolerate spikes in workload better than weaker athletes (OR: 1.33 – 5.10).
260 The current data is of practical significance to the workload-injury literature as it highlights the necessity
261 for conditioning and medical staff to appropriately load athletes within the gym to provide them with
262 the required strength and robustness to tolerate pitch and match-based loads. Previously, adequate
263 strength profiles have been associated with improved flexibility, running economy, maximal aerobic
264 speed, rate of force development, change of direction, jumping, and maximal speed ²⁰, all of which are
265 associated with improved ability to perform repeated intense exercise, a key component of team sport
266 competition. Therefore, coaches should be aware that improved strength will reduce subsequent injury
267 risk while also potentially improving athletic performance ²⁰.

268 The current investigation has observed that faster players over 5-, 10-, and 20-m were at reduced
269 risk of subsequent injury. The current data provides important considerations for coaches given that

270 anecdotally, exposure to maximal velocity is feared amongst many practitioners despite this quality
271 being considered to be critical for performance. Well-developed maximal velocity running abilities are
272 required of players during competition to beat opposition players to possession and gain an advantage
273 in attacking and defensive situations ²¹. In order to optimally prepare players for these maximal
274 velocities and high-speed elements of match-play, players require regular exposure to periods of high-
275 speed running during training environments ^{3,11}. Recent evidence suggests that lower limb injuries are
276 associated with excessive high-speed running exposure ²². However, the risk appears to be reduced
277 when players have well-developed aerobic fitness and chronic workloads ^{2,11}. Future research should
278 aim to assess the preventative nature of specific speed training methodologies to allow medical and
279 conditioning staff to select the most appropriate training method to enhance performance and reduce
280 injury risk. Overall, the current findings add further support to the notion of maximal velocity providing
281 a protective effect against injury. Coaches may aim to improve speed and thus reduce injury risk
282 through the application of training methodologies such as very heavy sled based training ²³. Previous
283 literature has shown the positive impact that the application of 80% body mass load through sled based
284 training can have on athlete's speed across distances of 5-m and 20-m respectively in team sport athletes
285 ²³.

286 We show for the first time that an athlete's ability to repeat maximal efforts over a short period
287 of time can protect them from subsequent injury risk. This would appear intuitive given that during both
288 training and match environments athletes can engage in movements that require them to repeatedly
289 produce maximal or near maximal efforts (i.e. sprints), interspersed with brief recovery intervals
290 consisting of complete rest or low- to moderate-intensity activity ¹⁸. While recently the external validity
291 of these tests has been questioned in team-sport environments ²⁴, we have observed that those athletes
292 with better RSA_t were at reduced risk compared to athletes with slower RSA_t (OR: 5.55, 95%: 3.98 –
293 7.94). Therefore, it would appear that improving a player's ability to tolerate repeated exposures to
294 maximal sprinting can in turn reduce their subsequent injury risk. As such while these events may be
295 rare within match-play, these tests offer medical staff the ability to stratify athletes into higher and lower
296 risk groups based on their repeated-sprint ability across a shortened period of time.

297 Factors in addition to weekly training loads and physical qualities such as previous injury, age
298 ²⁵, perceived muscle soreness, fatigue, mood, sleep ratings and psychological stressors ²⁶, are likely to
299 impact upon an individual's injury risk, however these were not accounted for in the current analysis.
300 Although sRPE has been shown to provide a valid indication of internal training load, it may
301 underestimate the average intensity of resistance exercise ²⁷, with fatigue potentially confounding the
302 relationship between RPE and relative intensity ²⁸. Although strength training sessions in the current
303 study comprised a limited amount of the global total training load, it is possible that the total training
304 load experienced by players may be slightly underestimated due to the mismatch between perceived
305 and actual resistance training intensity. Unfortunately, it was not possible to describe the external and

306 internal training loads of specific session types within the current study. Additionally, there is a need to
307 assess the utility of external:internal load ratios as a potential metric for injury risk assessment given
308 the known relationship between these ratios and fitness in team sport athletes^{29,30}. Finally, the model
309 developed within the current investigation will be best suited to the population from which it is derived.
310 Therefore, since this study involves a single team across a two-season period, it is difficult to translate
311 these findings to other teams across different training environments. Therefore, we recommend cross-
312 sport and cross-team analysis of testing and training load data to better understand the potential
313 moderators of the workload-injury relationship.

314

315 **CONCLUSION**

316 In conclusion, the present findings demonstrate that well-developed lower body strength, RSA
317 and speed were associated with better tolerance to higher workloads and reduced odds of injury within
318 team-sport athletes. When compared to a lower performance group those with greater strength, and
319 faster speed and RSA were consistently at reduced risk of injury. Coaches should aim to expose players
320 to training regimens that aim to improve these physical qualities to best moderate injury risk within
321 their own specific cohort of players. Given that the current investigation was completed with an amateur
322 cohort (i.e. 2-3 days training per week), our findings are likely to be relevant to coaches and practitioners
323 of sub-elite athletes.

324

325 **PRACTICAL APPLICATIONS**

- 326 • Speed, repeated-sprint ability and maximal strength are physical qualities that stratify injury
327 risk.
- 328 • Coaches should be aware that improved strength, repeated-sprint ability and speed will reduce
329 subsequent injury risk while also potentially improving athletic performance and therefore
330 should aim to develop training scenarios that allow these qualities to be trained consistently.
- 331 • We consistently observed that moderate weekly loads offered protective effects for athletes
332 across both the pre-season and in-season phases.

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416 **TABLE 1.** Relative lower body strength (Kg·Kg⁻¹) as a risk factor for injury above certain training and game load values. Data presented as OR
 417 (95% CI) when compared to a reference group.

Load Calculation In-Season	OR Exp (B)	95% Confidence Interval		p-Value
		Lower	Upper	
<i>Cumulative load (sum)</i>				
<i>1 weekly</i>				
<i>>1750 AU</i>				
3.0 (Reference)	1.00			
2.5 to 2.9	1.51	1.03	2.29	0.459
1.7 to 2.4	2.08	1.22	3.93	0.045
1.0 to 1.7	4.53	3.98	5.50	0.033
<i>Absolute Change (±)</i>				
<i>Previous to Current Week</i>				
<i>>550AU to 1000 AU</i>				
3.0 (Reference)	1.00			
2.5 to 2.9	2.54	1.04	2.97	0.487
1.7 to 2.4	3.53	2.66	3.88	0.011
1.0 to 1.7	4.52	3.98	4.92	0.023
<i>Acute:Chronic Workload (AU)</i>				
<i>>1.25 AU</i>				
3.0 (Reference)	1.00			
2.5 to 2.9	1.33	1.10	2.59	0.032
1.7 to 2.4	2.48	1.33	3.87	0.004
1.0 to 1.7	5.10	3.98	6.10	0.003

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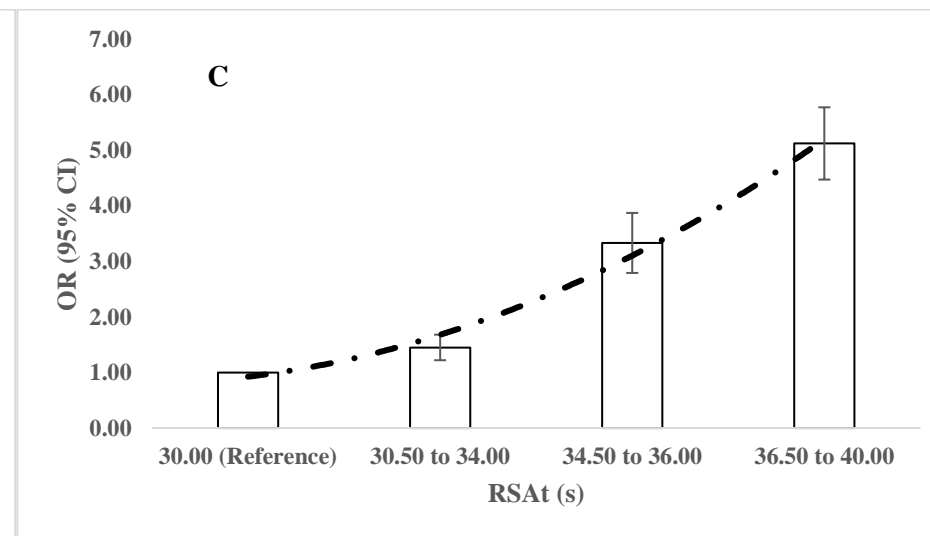
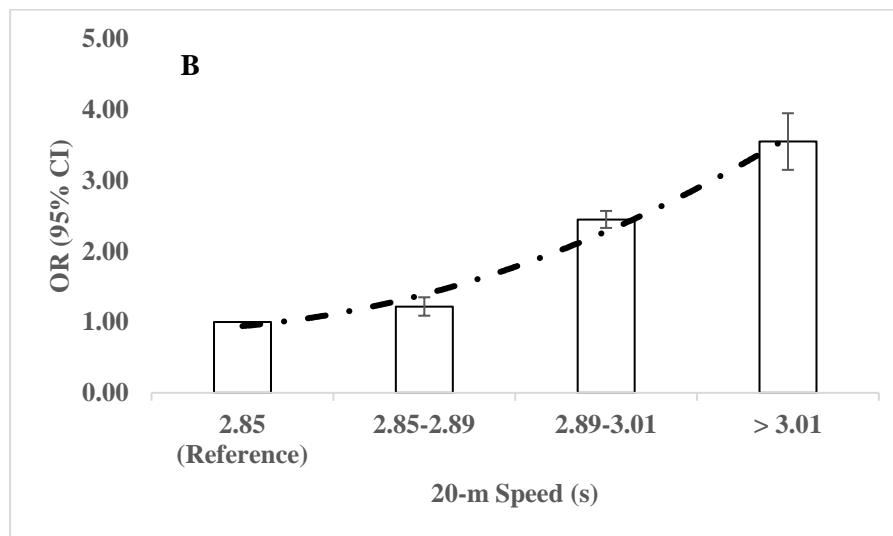
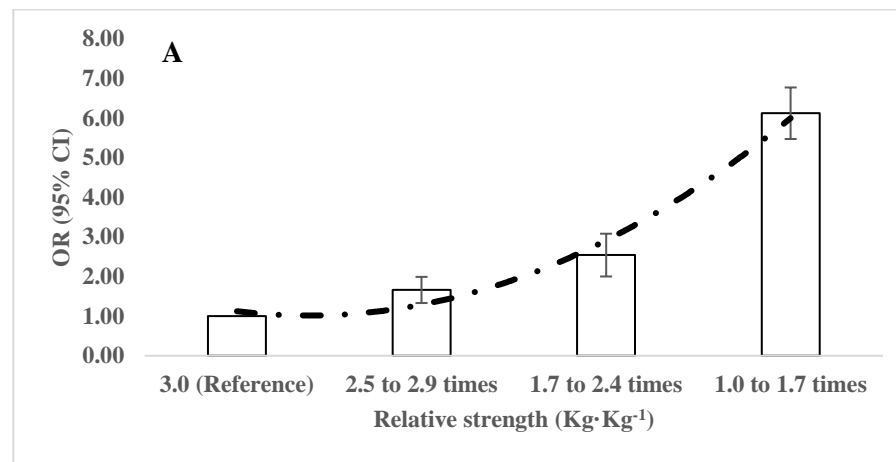
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422 **TABLE 2.** Speed over 5-, 10- and 20-m (s) as a risk factor for injury above certain training and game load values. Data presented as OR (95% CI)
 423 when compared to a reference group.

Load Calculation In-Season	OR Exp (B)	95% Confidence Interval		p-Value
		Lower	Upper	
Cumulative load (sum)				
<i>1 weekly</i>				
<i>>1750 AU</i>				
<i>5-m</i>				
0.88 (Reference)	1.00			
0.88 to 0.92	1.23	1.01	2.01	0.041
0.92 to 0.95	1.45	1.22	2.11	0.023
> 0.95	3.11	2.23	3.87	0.001
<i>10-m</i>				
1.75 (Reference)	1.00			
1.75 to 1.78	2.45	1.98	3.33	0.012
1.78 to 1.83	1.98	1.11	2.11	0.045
> 1.83	3.45	2.71	4.12	0.004
<i>20-m</i>				
2.85 (Reference)	1.00			
2.85 to 2.89	1.77	1.14	2.13	0.049
2.89 to 3.01	1.98	1.45	3.11	0.034
> 3.01	3.12	2.11	4.13	0.004
<i>Acute:Chronic Workload (AU)</i>				
<i>>1.25 AU</i>				
<i>5-m</i>				
0.88 (Reference)	1.00			
0.88 to 0.92	2.11	1.45	3.23	0.042
0.92 to 0.95	3.23	2.11	4.12	0.004
> 0.95	3.98	2.34	4.55	0.003
<i>10-m</i>				
1.75 (Reference)	1.00			
1.75 to 1.78	1.87	1.34	2.54	0.05
1.78 to 1.83	2.11	1.45	3.11	0.041
> 1.83	2.78	1.32	3.14	0.034
<i>20-m</i>				
2.85 (Reference)	1.00			
2.85 to 2.89	2.11	1.76	3.12	0.044
2.89 to 3.01	3.12	2.87	4.11	0.023
> 3.01	4.55	2.12	4.98	0.005

424 **FIGURE 1.** Relative Strength (a) Speed over 20-m (b) and RSA_t (c) as risk factors for injury independent of other factors. Data presented as OR (95%
425 CI) when compared to a reference group.



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430 **SUPPLEMENTARY TABLE 1.** Anthropometric and performance data. Data presented as mean \pm SD.

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Age (yr)	26.2 \pm 4.4
Height (cm)	184.2 \pm 7.1
Mass (kg)	82.6 \pm 4.7
3-RM Trapbar Deadlift (kg)	167 \pm 21
RSA (s)	32.12 \pm 1.23
5-m sprint time (s)	0.90 \pm 0.12
10-m sprint time (s)	1.83 \pm 0.23
20-m sprint time (s)	2.93 \pm 0.13

432 RSA; Repeated sprint ability

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444 **SUPPLEMENTARY TABLE 2.** Seasonal phase as a risk factor for injury across 1-weekly, 2-weekly, 3-weekly, 4-weekly and absolute change in
 445 cumulative training load. Data presented as OR (95% CI).

Cumulative Load (Sum) <i>RPE (AU)</i>	Training Load Component	Pre-Season (Dec-Feb)	In-Season (Mar-Oct)
	1 Weekly		
	≤ 1200 AU (Reference)	1.00	1.00
	Between 1200 AU - ≤ 1400 AU	1.95 (0.98 - 3.95)	3.95 (1.24 - 5.12)
	Between ≥ 1400 AU - ≤ 1900 AU	0.44 (0.18 - 0.66)	0.59 (0.37 - 0.82)
	≥ 2200 AU	2.12 (1.79 - 3.03)	0.33 (0.15 - 0.42)
	2 Weekly		
	≤ 2450 AU (Reference)	1.00	1.00
	Between 2450 AU - ≤ 2850 AU	1.68 (1.08 - 2.15)	4.98 (2.15 - 6.98)
	Between ≥ 2850 AU - ≤ 3250 AU	0.57 (0.28 - 0.77)	0.57 (0.15 - 3.12)
	≥ 4250 AU	3.64 (1.04 - 5.46)	0.44 (0.12 - 0.94)
	3 Weekly		
	≤ 3220 AU (Reference)	1.00	1.00
	Between 3220 AU - ≤ 3680 AU	2.67 (1.37 - 4.05)	3.55 (2.66 - 5.66)
	Between ≥ 3680 AU - ≤ 3950 AU	0.33 (0.09 - 0.95)	0.44 (0.23 - 0.66)
	≥ 3950 AU	3.22 (2.15 - 4.32)	2.11 (1.45 - 3.03)
	4 Weekly		
	≤ 3960 AU (Reference)	1.00	1.00
	Between 3960 AU - ≤ 4320 AU	3.41 (1.32 - 5.15)	2.21 (1.74 - 3.46)
	Between ≥ 4320 AU - ≤ 4950 AU	0.74 (0.23 - 0.94)	0.88 (0.34 - 1.52)
	≥ 4950 AU	4.33 (2.22 - 5.25)	3.31 (1.45 - 4.33)
	Absolute Change from previous week		
	≤ 150 AU (Reference)	1.00	1.00
	Between 150 AU - ≤ 30 AU	0.49 (0.50 - 1.98)	0.95 (1.02 - 3.99)
	Between ≥ 300 AU - ≤ 400 AU	0.66 (0.23 - 0.81)	0.99 (0.98 - 2.98)
	Between ≥ 400 AU - ≤ 1000 AU	2.44 (2.01 - 4.25)	1.54 (1.33 - 3.15)
	≥ 1000 AU	5.58 (3.19 - 7.32)	4.98 (2.33 - 5.36)

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450 **SUPPLEMENTARY TABLE 3.** Total repeated sprint time (RSA_t) as a risk factor for injury above certain training and game load values. Data
 451 presented as OR (95% CI) when compared to a reference group.

Load Calculation In-Season	OR Exp (B)	95% Confidence Interval		p-Value
		Lower	Upper	
<i>Cumulative load (sum)</i>				
<i>1 week</i>				
<i>>1750 AU</i>				
30.00 (Reference)	1.00			
30.50 to 34.00	1.86	0.59	1.00	0.459
34.50 to 36.00	3.08	1.16	4.99	0.045
36.50 to 40.00	5.55	3.98	7.84	0.033
<i>Absolute Change (±)</i>				
<i>Previous to Current Week</i>				
<i>>550AU to 1000 AU</i>				
30.00 (Reference)	1.00			
30.50 to 34.00	2.54	0.75	2.97	0.487
34.50 to 36.00	3.53	2.66	3.88	0.011
36.50 to 40.00	6.52	3.98	6.99	0.023
<i>Acute:Chronic Workload (AU)</i>				
<i>>1.25 AU</i>				
30.00 (Reference)	1.00			
30.50 to 34.00	1.02	0.26	2.59	0.032
34.50 to 36.00	2.48	1.33	3.87	0.004
36.50 to 40.00	5.10	3.98	6.10	0.003

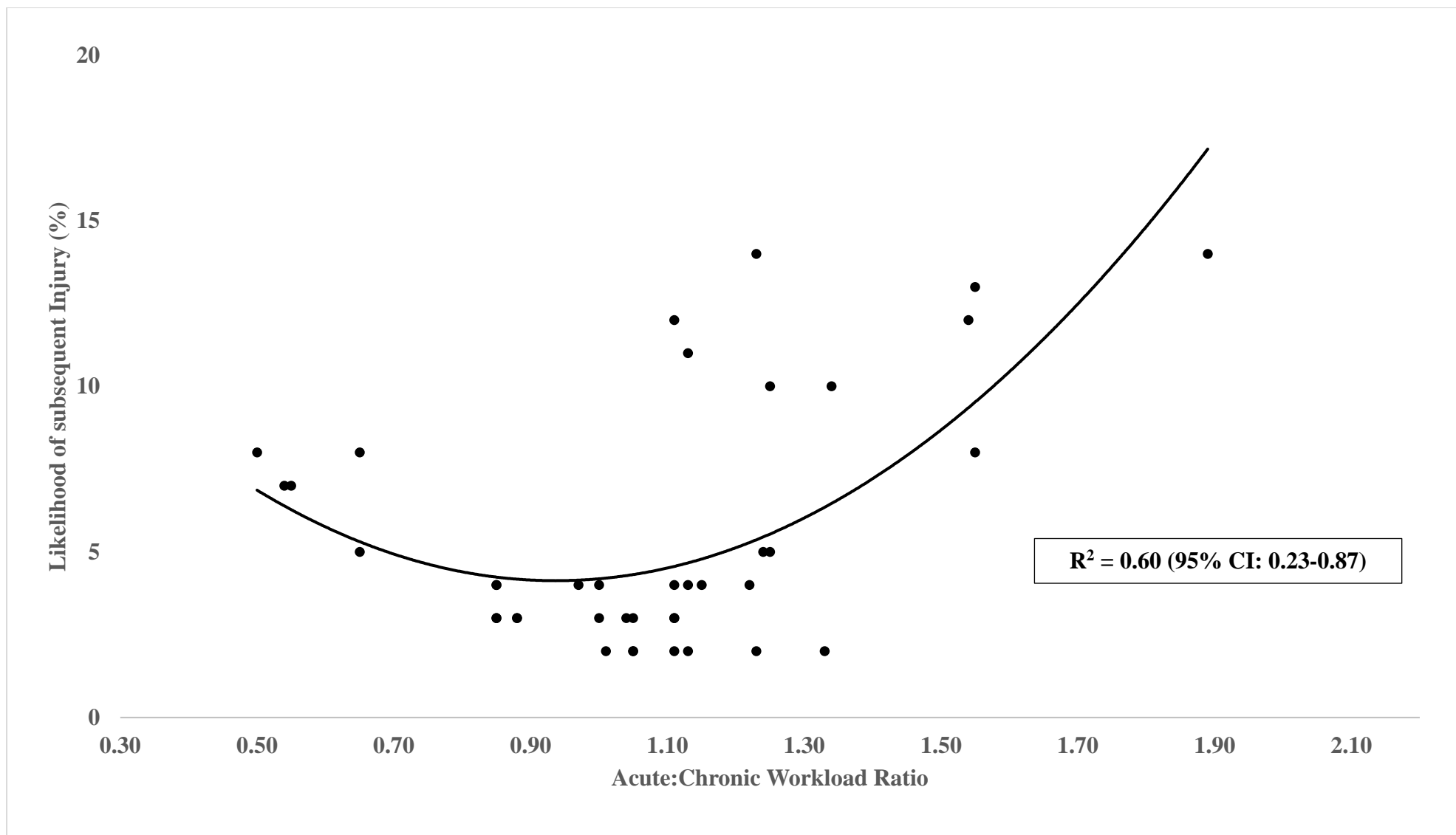
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456 **SUPPLEMENTARY FIGURE 1.** The acute:chronic workload ratio and subsequent injury likelihood in hurling players.



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