

1 **Title:** The Influence of In-Season Training Loads on Injury
2 Risk in Professional Rugby Union

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21 **ABSTRACT**

22 **Purpose:** To explore the association between in-season training
23 load measures and injury risk in professional Rugby Union
24 players. **Methods** This was a one-season prospective cohort
25 study of 173 Professional Rugby Union players from four
26 English Premiership teams. Training load (duration x session-
27 RPE) and time-loss injuries were recorded for all players for all
28 pitch and gym based sessions. Generalised estimating equations
29 were used to model the association between in-season training
30 load measures and injury risk in the subsequent week. **Results:**
31 Injury risk increased linearly with one-week loads and week-to-
32 week changes in loads, with a 2 standard deviation (SD) increase
33 in these variables (1245 AU and 1069 AU, respectively)
34 associated with odds ratios of 1.68 (95% CI 1.05-2.68) and 1.58
35 (95% CI: 0.98-2.54). When compared with the reference group
36 (<3684 AU), a significant non-linear effect was evident for four-
37 week cumulative loads, with a likely beneficial reduction in
38 injury risk associated with intermediate loads of 5932 to 8651
39 AU (OR: 0.55, 95% CI: 0.22-1.38) (this range equates to around
40 four weeks of average in-season training load), and a likely
41 harmful effect evident for higher loads of >8651 AU (OR: 1.39,
42 95% CI: 0.98-1.98). **Conclusions:** Players had an increased risk
43 of injury if they had high one-week cumulative loads (1245 AU),
44 or large week-to-week changes in load (1069 AU). In addition,
45 a 'U-shaped' relationship was observed for four-week
46 cumulative loads, with an apparent increase in risk associated
47 with higher loads (>8651 AU). These measures should therefore
48 be monitored to inform injury risk reduction strategies.

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58 INTRODUCTION

59 The aim of training is to optimise performance through the
60 mastery of sport specific skills and advancing physical
61 conditioning. However, the process of applying appropriate
62 training loads (a product of training intensity, volume/duration
63 and frequency) is a constant challenge for coaches, particularly
64 in the context of season-long team sports¹. Whilst increasing
65 training loads is generally thought to improve athletic
66 performance², it may also increase player fatigue and injury
67 risk³. Injury impacts on individual's ability to train and compete,
68 and higher injury burden has been associated with poorer team
69 success in professional football cohorts^{4,5}. As such, the
70 prescription of appropriate training loads requires a careful
71 consideration of the positive (fitness and skill development) and
72 negative (fatigue and injury risk) response⁶.

73 Many studies have looked at the training load-performance
74 relationship in sport^{1,2,7}, but a far smaller number have
75 investigated the association between training loads and injury in
76 contact sports, especially within an elite population. Previous
77 studies^{3,8-10} have shown that a reduction in training load in-
78 season resulted in a reduction in the incidence rate of injuries.
79 One of these studies⁹ suggested that a player's threshold (the
80 amount of training load that could be sustained by the player
81 before an injury occurred) decreased during the season,
82 potentially as players became fatigued when compared to pre-
83 season thresholds. Higher weekly and two weekly cumulative
84 loads and absolute week-to-week changes in load have been
85 associated with an increased risk of injury in Australian
86 Football¹¹. Players who experienced a change in previous to
87 current week load of >1250 AU (~75% change) were 2.58 times
88 more likely to be injured in comparison with the reference group
89 of a <250 AU (~15% change) . Furthermore, elevated three-
90 weekly cumulative loads derived from Global Positioning
91 Systems (GPS) measurements were also associated with an
92 increased risk of injury in this population¹².

93 A small number of studies have investigated the relationship
94 between training volume (duration of training) and injury risk in
95 Rugby Union^{13,14}. Brooks and colleagues¹³ found that the mean
96 training volumes for pre-season and in-season were 9.2 and 6.3
97 hours respectively with more time spent on conditioning in pre-
98 season and skills training in season¹⁵. The lowest number of days
99 lost due to injuries occurred during weeks of intermediate

100 training volume (6.2 - 9.1 hours per week). A higher training
101 volume (> 9.1 hours per week) did not increase injury incidence
102 rates but did increase the severity of match injuries. In addition,
103 Viljoen and colleagues¹⁴ recorded training volumes within a
104 professional team over a three year period and concluded that a
105 reduction in training volume over three seasons was associated
106 with slight reduction to in-season injury rates. However, it was
107 noted that the team's league position also changed from 3rd to 7th
108 (2002-2004) and thus, did not recommend reducing training
109 volumes too much as the players may no longer be exposed to
110 the required training stimulus in order to be able to compete
111 effectively during matches.

112 It is likely that the training load-injury relationship for each sport
113 is unique, given the different periodisation patterns and physical
114 demands of training and match-play imposed upon players. To
115 date, training load has not been investigated as a modifiable risk
116 factor for injury in Rugby Union. Advances in our understanding
117 of this area will enable coaching staff to have more confidence
118 that the training loads that they prescribe do not significantly
119 increase a player's risk of injury. Accordingly, the purpose of the
120 present study was to explore the association between selected
121 training load measures and injury risk in professional Rugby
122 Union players.

123 **METHODS**

124 **Participants**

125 This was a prospective cohort study of Professional Rugby
126 Union players registered in the first team squad of four teams
127 competing at the highest level of Rugby Union in England
128 (English Premiership). Data were collected for 173 players (team
129 A = 43 players, team B = 41 players, team C = 46 players, team
130 D = 43 players) over one season (2013/14). The study was
131 approved by the Research Ethics Approval Committee for
132 Health at the University of Bath and written informed consent
133 was obtained from each participant.

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136 **Procedures**

137 All time-loss injuries were recorded by the medical personnel at
138 each team using the Rugby Squad medical database (The Sports
139 Office UK, 2011). A modified version of the Orchard sports

140 injury classification system OSICS¹⁶ was embedded within the
141 medical system and was used to code each injury diagnosis.
142 Reported time-loss injuries were included in the study if they
143 occurred in training or 1st or 2nd team competitive matches and if
144 they met the 24-hour time-loss definition¹⁷.

145 The intensity of all training sessions (including rehabilitation
146 sessions) were estimated using the modified Borg CR-10 RPE
147 (Rate of Perceived Exertion) scale¹⁸, with ratings obtained from
148 each individual player within 30 minutes after the end of each
149 training session¹⁹. A member of each club's strength and
150 conditioning staff was allocated to be in charge of the club's data
151 collection, they were then briefed on the intensity scale and all
152 clubs were given the same scale to use during the season. Each
153 player had the scale explained to them by their strength and
154 conditioning coach before the start of the season and players
155 were asked to report their RPE for each session confidentially to
156 the strength and conditioning coach without knowledge of other
157 players' ratings. Session RPE in arbitrary units (AU) for each
158 player was then derived by multiplying RPE and session
159 duration/volume (min). Session RPE has previously been shown
160 to be a valid method for estimating exercise intensity²⁰ and
161 returned positive correlations of 0.89 and 0.86 with training heart
162 rate and training blood lactate concentrations, respectively,
163 during typical Rugby League training activities¹⁰. Thus, the
164 session RPE method was an inexpensive, simple and highly
165 practical approach that allowed valid and reliable measures of
166 each player's internal response to both pitch-based and gym-
167 based training sessions²¹. These data were collated and sent to
168 the project leader on a monthly basis by strength and
169 conditioning staff.

170 The competitive season was split into two distinct phases for
171 descriptive purposes, namely: 'pre-season' (between 8-11 weeks
172 dependent on when each club commenced their season) and in-
173 season (36 weeks). The in-season phase was then split into
174 'early-competition' (first 18 weeks of the competitive season)
175 and 'late-competition' (last 18 weeks of the competitive season),
176 to ascertain if there were any differences in training loads
177 between these phases as differences may exist in training
178 objectives between early and late in-season competition. ⁹. In
179 addition to weekly training load (sum over each 7-day period,
180 commencing Monday of: session intensity [RPE] x session
181 duration [mins]), a number of other training load measures were
182 derived based on previous studies: a) cumulative two, three and

183 four weekly loads calculated by the sum of the previous weeks'
184 training loads¹¹; b) week-to-week change in loads (absolute
185 change in a players current load from that of the previous
186 week)¹¹; c) weekly training monotony (weekly mean/standard
187 deviation)²²; d) weekly training strain (weekly training load x
188 training monotony)²²; and e) training stress balance (a player's
189 acute (one week) workload divided by their chronic (four week
190 rolling average) workload)²³.

191 **Statistical Analysis**

192 Data were analysed in SPSS Version 22.0 (IBM Corporation,
193 New York, USA). A two-way (Phase × Team) mixed analysis of
194 variance (ANOVA) was used to identify differences in training
195 loads between phases of the season, and between teams.
196 Generalised estimating equations were used to model the
197 association between in-season (early and late competition phases
198 combined) training load measures and injury in the subsequent
199 week, using a binary distribution, logit link function, first-order
200 autoregressive (AR1) working correlation structure, and offset
201 for players' individual match exposure. Based on the data
202 supplied by one team in this study, our observations suggest
203 there is very little variation in reported RPE for matches (i.e. the
204 vast majority of players reported 9-10), and so match exposure
205 was the key distinguishing element between players. Individual
206 match exposure was therefore accounted for, but did not
207 contribute to training load values. This model was selected for
208 its ability to account for intra-player and intra-team cluster
209 effects²⁴. If assessment of a quadratic trend between the training
210 load measure and injury risk was significant ($P \leq 0.05$), training
211 loads were sorted from smallest to largest and the measure was
212 split into quartiles for analysis, with the lowest load range being
213 the reference group to enable us to compare the risk of injury at
214 intermediate, higher intermediate and high loads compared with
215 low loads. Otherwise, linear effects for continuous predictor
216 variables were evaluated as the change in injury risk (Odds Ratio
217 [OR]) associated with a two standard deviation increase in the
218 training load measure²⁵. Correlation coefficients between the
219 training load measures, alongside Variance Inflation Factors
220 (VIF), were used to detect multicollinearity between the
221 predictor variables. A VIF of ≥ 10 was deemed indicative of
222 substantial multicollinearity²⁶.

223 Magnitude-based inferences were used to provide an
224 interpretation of the real-world relevance of the outcome²⁷. The

277 DISCUSSION

278 This is the first study to investigate the association between
279 training load measures and injury risk in professional Rugby
280 Union players. The results of this study suggest that a positive
281 linear relationship exists between both weekly training load and
282 absolute week-to-week changes in load and subsequent injury
283 risk during the in-season phase. In addition, a ‘U-shaped’
284 relationship between four-week cumulative loads and injury risk
285 was identified. These findings suggest that weekly training
286 loads, week-to-week changes in load, and 4-week cumulative
287 loads could be adapted by professional Rugby Union teams in
288 order to reduce injury risk in this setting.

289 The mean weekly training loads described in this study were
290 smaller than those previously described in professional Rugby
291 Union³⁰ and Rugby League³, but were similar to those observed
292 in professional Australian Rules Football¹¹. A two standard
293 deviation (or 80% based on an average in-season week) increase
294 of in-season weekly load (1245 AU, approximately a 4 hour
295 increase of an average in-season training intensity [RPE=5])
296 was associated with around a 70% increase in injury risk in the
297 subsequent week. This finding is consistent with the majority of
298 previous research in contact sports^{3,8,11}, and may be related to the
299 impact of fatigue and concomitant changes in neuromuscular
300 control³¹.

301 In agreement with the findings of Rogalski and colleagues¹¹
302 absolute changes in week-to-week loads increased the risk of
303 injury, with an absolute change in load of 1069 AU (about 3.5
304 hours of average in-season training intensity during this study)
305 associated with an approximate 60% increase in the risk of injury
306 the following week. This is important from a practical
307 perspective as sudden training load increases could be imposed
308 on players who are returning to training from injury. Equally,
309 sudden decreases in week to week load could be associated with
310 players who have to undertake modified training regularly, often
311 in order to manage a chronic injury. Clubs should re-integrate
312 players (injured or otherwise) back into training in a
313 conservative manner, whilst carefully monitoring their training
314 load in order to prevent a high weekly change in load and
315 ultimately reduce the risk of injury (or subsequent injury in the
316 case of injured players). However, it is noted that in practice the
317 consistent application of this recommendation can prove

318 difficult as coaches typically hope that any player will be able to
319 train without restriction with the rest of the training squad as
320 soon as they are able to do so. Training stress balance, which
321 expresses acute workloads (i.e. 1-week data) against chronic
322 workloads (i.e. 4-week rolling average), may be a useful means
323 of monitoring this aspect of loading. The association between
324 training stress balance and injury risk in the present study was
325 unclear, and so further data are required to confirm its utility in
326 this setting.

327 Previous studies in professional contact sport have reported a
328 positive linear relationship between cumulative loads and injury
329 risk^{11,12}. The present study is the first to present a non-linear
330 association between cumulative training loads and injury risk,
331 but a similar relationship has been observed previously with
332 average weekly training volume (duration only) and injury risk
333 in professional Rugby Union players¹³. A ‘U-shaped’
334 relationship between four-week cumulative loads and injury risk
335 was identified. Four-week loads were associated with a decrease
336 in the likelihood of injury in the ‘high intermediate’ quartile
337 (5932 to <8651 AU) in comparison to the ‘low’ reference
338 quartile (<3684 AU), however injury risk increased substantially
339 thereafter for ‘high’ loads (≥ 8651 AU). Given that the mean in-
340 season weekly training loads were ~ 1500 AU, four weeks of
341 training would equate to ~ 6000 AU and would sit within the
342 third quartile of four week cumulative loads. It can be reasonably
343 assumed that the players within this quartile are likely to have
344 been training regularly during the four week period and will have
345 acquired an appropriate level of fitness and physical robustness,
346 which may explain the reduction in injury risk for this group. It
347 is likely that the training loads exhibited in the ‘high
348 intermediate’ quartile group reflect a training load that best
349 allows players to adapt to a performance training stimulus
350 without substantially increasing injury risk^{11,32}. The increase in
351 risk associated with players in the ‘high’ quartile for load (>8651
352 AU) suggests that players are likely to have an individual range,
353 above which they are substantially more likely to incur an injury.
354 The pre-season training loads reported in this study (2175 ± 380)
355 AU are around half of those previously reported in professional
356 rugby league³. These low pre-season loads may have meant that
357 players were unable to tolerate in-season training loads in the
358 highest 4-week quartile as they had not been exposed to similar
359 loads previously. Conversely, excessive cumulative fatigue
360 (adaptation without sufficient recovery) may lead to a reduction

361 in the amount of stress that tissues can cope with and thus,
362 beyond a certain threshold of load, the risk of injury increases³³.
363 It is not possible to say if the increase in in-season injury risk
364 observed in the highest quartile is due to insufficient recovery
365 time during high cumulative loads or, if players were
366 inadequately prepared to cope with the loads in this quartile due
367 to the low level of pre-season training loads prescribed. It is
368 likely that both these factors contributed to an increase in injury
369 risk in this study.

370 There is a clear requirement for coaches to achieve a balance
371 between simultaneously allowing exposure to an adequate
372 training stimulus in order to prepare the player for the specific
373 demands of their sport and to subsequently improve
374 performance^{2,14} whilst limiting a player's load in order to prevent
375 injury. This is particularly important in contact sports whereby
376 practitioners need to prepare players to be able to cope with the
377 demand of contact events whilst managing their overall risk of
378 contact injury. One way that this might be achieved in practice
379 is by reducing training monotony. It has been suggested that
380 players may be able to manage high daily training loads as long
381 as they are dispersed between lower load training days and/or a
382 day off during the training week²². The association between
383 training monotony and injury risk in the present study was
384 unclear, and this measure should be explored with larger samples
385 in future studies.

386 **PRACTICAL APPLICATIONS**

387 This study is the first to provide an indication of how players'
388 weekly training load is associated with injury risk in professional
389 Rugby Union. Team coaches should monitor a player's weekly
390 load, week-to-week changes in load and four-week cumulative
391 load, when planning and implementing training to optimise
392 performance whilst minimising injury risk. Given that these
393 findings suggest that a high load and a large absolute change in
394 load increase the risk of injury in professional Rugby Union
395 players, trying to periodise training schedules with alternating
396 heavy and light training weeks is not recommended (as opposed
397 to alternating heavy and light days which requires further
398 investigation). One way that this may be achieved in practice is
399 for coaches to prescribe stable and consistent weekly loads
400 throughout the season in order to prevent any spikes in acute
401 workload. Our results also suggest that professional players may
402 have a four-week cumulative training load limit, and that

403 exceeding this threshold is associated with a substantial increase
404 in injury risk. Strength and conditioning coaches should use
405 these findings as a starting point for planning and monitoring
406 individual player training thresholds. The physiological
407 demands and movement patterns of different sports vary
408 significantly and any application of these findings in other
409 populations should be performed with caution.

410

411 **LIMITATIONS**

412 Factors in addition to training and match load are likely to impact
413 upon an individual's injury risk, such as previous injury³⁴ and
414 psychological stressors³⁵, and these were not accounted for in the
415 analysis. Given that only a small number of reported injuries and
416 match exposure was reported during the pre-season phase, these
417 training loads were not included in the model used to investigate
418 the association between training load measures and injury risk.
419 The impact of this phase should be investigated in future studies.
420 The day, week and phase of the season were reported clearly by
421 all clubs, however, only total load values were collected rather
422 than information pertaining to the specific type of training
423 modality used in each session. Unfortunately, it was therefore
424 not possible to describe the training load values of specific
425 session types in this study. In addition, information regarding the
426 association between training load and specific types of injury
427 (e.g. soft tissue injuries) could not be investigated due to the
428 sample size (and associated statistical power) available in the
429 current study, this warrants future investigation. No meaningful
430 conclusions could be drawn regarding training monotony or
431 training stress balance as risk factors for injury. These load
432 variables should be investigated in future using a more
433 statistically powerful sample. Furthermore, whilst the session-
434 RPE method has been proposed as an acceptable method of
435 quantifying training load in collision sports²¹, GPS measures
436 might provide additional data regarding external total training
437 load. In this context, some training activities (skills, wrestling,
438 strongman and speed sessions) may be better quantified using a
439 combination of internal- and external-load measures.

440 **CONCLUSIONS**

441 This study is the first to show an association between training
442 load and risk of injury in professional Rugby Union. Players
443 were at an increased risk of injury if they had a high one week

444 cumulative load or a large week-to-week change in load. A ‘U-
445 shaped’ association between four-week cumulative loads and
446 injury risk was identified. The ‘high intermediate’ quartile of
447 four-week cumulative load 5932 to <8651 AU (in a practical
448 sense, the lower limit of this range equates to around four weeks
449 of average in-season training load) would appear to be beneficial
450 in reducing injury risk in this population. These measures should
451 therefore be individually monitored in professional Rugby
452 Union players, as a potential means of informing risk reduction
453 strategies in this setting.

454 **ACKNOWLEDGEMENTS**

455 The authors would like to acknowledge with considerable
456 gratitude the players, coaches and medical staff for the recording
457 of training load and injury data throughout the study period.

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613 **Table and Figure Captions**

614 **Figure 1.** Mean weekly training loads (AU) by team for each
615 phase during the 2013-14 season with error bars showing
616 standard deviation (e.g. four sessions of RPE=7 and 45 minute
617 duration would produce a training load of 1260 AU).

618 **Table 1** . Training load risk factors for injury in professional
619 Rugby Union.

620 **Figure 2**. Four weekly cumulative training load quartiles and the
621 likelihood of injury [%]. * denotes substantial change in injury
622 risk in comparison with reference group (<3684 AU).

Table 1 .

Load calculation	2 SDs	Effect of 2 SD increase	95% Confidence intervals		P-Value	Inference	% likelihood effect is beneficial trivial harmful
		[Odds ratio]	Lower	Upper			
1 week cumulative load	1245 AU	1.68	1.05	2.68	0.003	Very likely harmful	0 1 99%
Absolute change (±)	1069 AU	1.58	0.98	2.54	0.06	Likely harmful	1 6 93%
Monotony	0.39	1.22	0.84	1.78	0.29	Unclear	5 26 69%
Training stress balance	172%	1.41	0.60	2.80	0.42	Unclear	15 14 71%
4 week cumulative load							
<3684 AU (reference)		1.00					
3684 to <5932 AU		0.79	0.48	1.29	0.34	Unclear	70 21 9%
5932 to <8651 AU		0.55	0.22	1.38	0.20	Likely beneficial	85 8 7%
≥8651 AU		1.39	0.98	1.98	0.06	Likely harmful	1 9 90%

