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

3 **Submission Type:** Original Investigation

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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

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

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

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

smallest worthwhile increase in risk (i.e. harmful effect) for time-loss injuries was an odds ratio of 1.11, and the smallest worthwhile decrease in risk (i.e. beneficial effect) was 0.90²⁸. An effect was deemed unclear if the chance that the true value was beneficial was >25%, with odds of benefit relative to odds of harm (odds ratio) of <66 (or vice versa). Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following scale : <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely²⁹.

235 RESULTS

In total, 465 time-loss injuries (303 match, 162 training) were reported across the 4 teams during the season. Overall, match injury incidence was 101.7/1000 hours, 95% CI: 90.9-113.8) and training injury incidence was (3.3/1000 hours, 95% CI: 2.8-3.8). The total match and training volumes reported during the season were 2980 hours and 51653 hours respectively.

The two-way mixed ANOVA showed significant ($P < 0.01$) effects for Team, Phase, and Phase $\times$ Team. Average weekly training loads decreased from pre-season (2175 ± 380 AU), to in-season, with no significant differences between early-competition (1522 ± 203 AU) and late-competition (1581 ± 317 AU) phases (figure 1).

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>>>>>>>>>>>>>>Figure 1 <<<<<<<<<<<<<<<

Weekly training strain and two- and three-weekly cumulative loads displayed substantial multicollinearity with other training load measures, and so were excluded from the analysis. The small number of injuries (n=24) and match exposure (200 hours) during the pre-season period in this study produced unstable estimates (i.e. large standard errors) thus; the pre-season loading data are only presented for information and were not included in the model. As there was no significant difference in the training loads between in-season early and late competition phases, all in-season loads were included in the model. During the in-season phase, risk of injury in the subsequent week increased linearly with one-week loads and absolute change in loads, with a two standard deviation rise in these variables (1245 AU and 1069 AU, respectively) being associated with an increase in the odds of injury of 1.68 (95% CI 1.05-2.68) and 1.58 (95% CI: 0.98-2.54), respectively (Table 1). The change in injury risk

276 >>>>>>>>>>>>>>>Figure 2<<<<<<<<<<<<<<<<<

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]) was
 296 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

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

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

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

LIMITATIONS

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

CONCLUSIONS

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

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

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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		<i>P</i> -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%