Training Load, Injury Burden, and Team Success in Professional Rugby Union: Risk Versus Reward

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Context: Individual and team injury burden and performance are 2 key considerations facing practitioners in the daily prescription of an athlete's training load. Whereas a considerable number of researchers have examined univariate relationships between training load and performance, training load and injury, or injury and performance, few investigators have examined all 3 concurrently.

Objective: To assess the association among training load, injury burden, and performance in professional rugby union.

Design: Descriptive epidemiology study.

Setting: The English Premiership competition.

Patients or Other Participants: Individual injury and training load data, as well as team performance data, were captured during the 2015–2016 (n = 433 players) and 2016–2017 (n = 569 players) seasons.

Main Outcome Measure(s): Data were aggregated into team average scores for each week, including weekly (acute) load, smoothed chronic load, changes in load, injury burden, and weekly performance. Linear mixed modelling techniques were used to assess the association among measures.

Results: Injury burden was negatively associated with performance, with a high weekly burden associated with a likely harmful (P = .01) decrease in performance. Training load measures displayed only trivial associations with performance. Only the acute:chronic workload ratio measure was clearly associated with injury burden, with a possibly harmful effect (P = .02). Both squad size and player availability were associated with only trivial changes in performance.

Conclusions: Whereas no association between average training load and performance existed, associations between training load and injury burden and between injury burden and performance were clear. Further investigation using more sensitive and individualized measures of load, performance, and injury may elicit a clearer relationship and should be considered for future work.

Key Words: performance, management, injury, workload

Key Points

- Injury burden was negatively associated with performance, but training load measures demonstrated only trivial associations with performance.
- Only the acute:chronic workload ratio variable was associated with injury burden.
- Irrespective of the training load measure used, the lowest injury burden category was associated with the highest performance level.
- Squad size and player availability were associated with only trivial changes in performance.
- Measures of performance need to be built into research on training load and injury.

The interaction among workload, injury, and performance is central to managing athletes in team sports. Despite this, the definitions, monitoring, and analyses of these metrics lack consensus in both practical and research settings. In rugby union, *load* has been defined as "the total stressors and demands applied to the players,"[1] whereas *physical load* has been defined as "the cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time."[2] Similarly, numerous definitions for injury within and between sports exist, varying from inclusive definitions, such as any physical concern,[3] to more exclusive definitions, such as those resulting in missed matches.[4] Comparing studies is challenging because different definitions for each variable are likely to alter the nature of the relationships among variables.[5]

In both sport and research settings, performance can be either a behavior or an outcome. Performance as a behavior can be measured by sports statistics,[6] key performance indicators,[7] physical fitness improvements,[8] subjective coach ratings, or physical performance outputs.[9] Performance as an outcome is often referred to as *sporting success* and can be measured by league position,[10] ranking systems,[7,11] or the winning of a specific game event or competition.[7]

Given the increasing use of scientific principles to monitor athletes, research exploring associations among injury, performance, and load has increased. Of these associations, the evidence surrounding injury and perfor-

mance is clear, with low injury outcomes linked to improved team success in multiple sports,[7,12] including rugby union.[11,13] Despite several systematic reviews[14,15] in which the association between injury and load has been outlined, current evidence is mixed; the relationship appears to be affected by the sport being studied, the load variables included in the analysis, and the definition of injury. In the context of the load-performance relationship, although authors of one study[6] demonstrated clear associations, authors of a recent systematic review[16] outlined little evidence for a link between external training load and performance. Furthermore, in rugby union, training volume was not associated with final league position.[10]

The purpose of this study was to establish whether associations among training load, injury burden, and performance exist within rugby union. Whereas previous researchers in this area considered load, injury, and performance separately, we explored how the 3 areas interact, addressing the need to find a balance between minimizing injury risk and maximizing performance potential.

METHODS

Participants

Data were collected from 13 Premiership rugby clubs over the 2015–2016 and 2016–2017 seasons (10 clubs, 2 seasons; 3 clubs, 1 season). Individual load and injury data were captured for 433 and 569 players in each respective season (1002 player-seasons for 696 individual players). Injury data were obtained as part of the Professional Rugby Injury Surveillance Project. Players were included only if both injury and detailed training exposure were collected. Each player was provided with a participant information sheet. The study was approved by the University of Bath Research Ethics Approval Committee for Health (Reference no. 15/16 252), and each player provided written informed consent.

Procedures

Data on 24-hour time-loss injuries[17] were gathered by club medical staff through an online data-collection platform (Rugby Squad; The Sports Office UK Limited, Wigan, United Kingdom). Training and match load data were captured for every session undertaken by each athlete using the session rating of perceived exertion.[18] When possible, within 30 minutes of completing the session, each player was instructed to rate his perceived session exertion on a scale from 1 (*very, very easy*) to 10 (*maximal*),[19] and this value was multiplied by the session's duration (in minutes) to give a session rating of perceived exertion load score. These data were captured by sports science or conditioning staff in the clubs after a session to ensure that a measure of load for the session as a whole was provided.[18]

To calculate a weekly measure of performance, we gave each week's game a match difficulty index (MDI),[20,21] which we multiplied by the outcome (points difference: positive or negative) of the game being measured. To calculate the MDI for a given match, investigators[20] have suggested 3 fixed factors (opposition rank in the previous season, match location [home, away], days of turnaround between fixtures) and 6 dynamic factors (opposition rank in

the current season, difference in league positions, team form [team performance over a given period before the match of interest], number of team changes in the previous week, number of team changes in the past 4 weeks, and number of players in the first season of their careers). However, given the complexity involved in assembling the final 3 dynamic factors league wide, only the first 6 factors (3 fixed, 3 dynamic) were used in this study. Using these 6 factors, we conducted binary logistic regression, with the dependent variables of win (1) or loss (0); games ending in a draw were excluded from analysis (11 games over 2 seasons).[20] Subtracting the logit probability value of a win from 1 and multiplying the difference by 10 provided each game with an arbitrary unit value of 1 to 10, with an MDI of 1 representing an easier match than an MDI of 10. To obtain a performance score for each week, we multiplied the MDI by the points difference in the game. If the outcome of the game was a loss, the inverse of the MDI was used so that a loss against a team with a high MDI (less chance of winning) was given a better performance score than a loss against a team with a low MDI (higher chance of winning). To provide a simple metric for analyzing European games, we gave Champions Cup (the highest tier of European rugby) matches the average MDIs for playing a team that finished in the top 6 teams in the Premiership table in the previous season (home or away). Challenge Cup (second-tier) games were assigned the average MDIs for playing a team from those ranked 7 to 12 in the previous season (home and away). This meant that a standard MDI existed for all home and away games for Champions Cup and Challenge Cup fixtures for the 2 seasons.

In any specific week, only training and injury data for players selected for the match-day 23-player squad were included in the study. The weekly injury value designated for each team was that of injury burden (number of days absent per 1000 hours of exposure), which accounted for both injury incidence and severity.[22] The injury burden in the match-day 23-player group each week represented predominantly match injury burden and any burden from low-severity training injuries that occurred early in the week, because any serious injury burden during that week would rule out a player for selection in that week's fixture. Therefore, that injury burden in this study was likely to have a greater effect on in-game tactics and a lesser effect on preparation in any given week.

Statistical Analysis

Individual injury and load data were collated to provide a weekly value for each team over the course of the season. Average weekly (acute) load, average smoothed chronic load, and the average acute:chronic workload ratio (ACWR; average weekly load / average smoothed chronic load) were calculated for each week. The smoothed chronic loads were calculated using an exponentially weighted 4-week average as described by Williams et al.[23] The *z* score for each of the average weekly and smoothed chronic loads was calculated to standardize training weeks within each team. Given that most competitive fixtures occur between Friday and Sunday, each new weekly value began on Monday; thus, the mean scores for each week included 1 game exposure. All statistical analyses were performed

Table. Descriptive Statistics for Training, Injury, and Performance Measures

Measure	Mean ± SD
Weekly load, arbitrary units	2032 ± 629
Smoothed chronic load, arbitrary units	1943 ± 539
Acute:chronic workload ratio	0.96 ± 0.30
Injury burden, d	84 ± 106
Player availability, %	85 ± 7
Squad size, No. of players	57 ± 5
Smallest worthwhile change	
Performance, arbitrary units	11.7
Injury, d absent per 1000 h	21.3

using RStudio (version 1.0.136; RStudio, Boston, MA). All modelling was undertaken using the lme4 package (RStudio),[24] and 90% confidence intervals (CIs) for marginal means were produced using a bootstrapping method in the bootMer package (RStudio).[24] Linear mixed models were used with load measures (average weekly, smoothed chronic, ACWR) and performance (arbitrary score) as the independent and dependent variables, respectively. The distribution of the injury burden demonstrated clear negative skew to the left, so generalized linear mixed models were used with a γ distribution and log link function in any case in which the dependent variable was injury burden. Club was included as a random effect in the models to account for differences among clubs. Player availability (as a percentage) and squad size were modeled against performance to identify whether inclusion in the linear mixed models would moderate the association between the main outcome variables. Quadratic terms were included in each separate model to identify whether nonlinear tendencies were apparent. Variables showing nonlinearity were split into quartiles of equal sample size to assess the effect on outcome variables, whereas variables demonstrating only linear relationships were evaluated per a 2-SD change in the predictor.[25] Magnitude-based inferences were used to assess the importance of the model estimates, which were based on effect size and corresponding CIs in relation to a smallest worthwhile change. The smallest worthwhile change was calculated as 0.2 of the SD in the model dependent variables (injury burden = 21.3 units and performance = 11.7 units). Unclear effects were reported if the 90% CIs crossed the threshold for both harm and benefit by 5%.[25] If the effect was clear, it could be termed *beneficial*, *harmful*, or *trivial* (less than the smallest worthwhile change), with the strength of the effect expressed as a qualitative probabilistic term using the following thresholds: <0.5%, *most unlikely*; 0.5% to 5%, *very unlikely*; 5% to 25%, *unlikely*; 25% to 75%, *possibly*; 75% to 95%, *likely*; 95% to 99.5%, *very likely*; or >99.5%, *most likely*.[25] Given the recent criticism concerning the use of magnitude-based inferences,[26] to allow readers their own interpretations of the findings, the effect estimate, CI, and *P* value (α level set at .05) associated with each effect have been included. This enables advocates of both null hypothesis testing and magnitude-based inferences to understand the magnitude and certainty of the effect in each case.

RESULTS

The mean squad size was 57 ± 5 players, and the mean percentage availability was 85% ± 7%, meaning that on
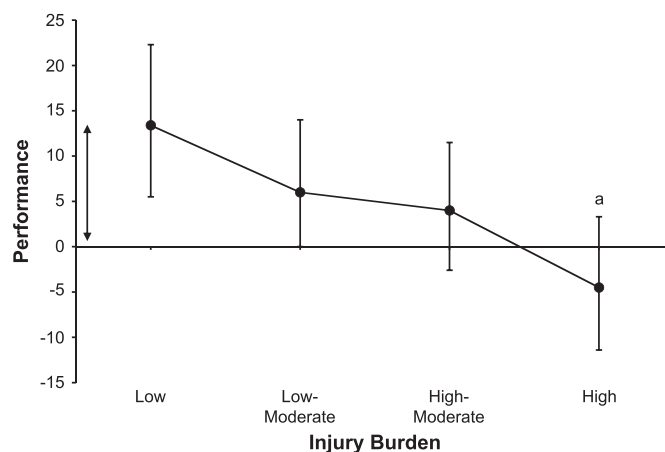

Figure 1. Association between injury burden and performance with 90% confidence intervals. The arrow indicates the smallest worthwhile change[6] in performance = 11.7 units. It is anchored on the first value on the graph and points below that point in the same direction of the relationship. ª Clear difference between reference group and group of interest.

average, teams had 48 players from whom to select on a weekly basis (Table). The mean weekly injury burden was 84 ± 106 days, and the mean performance score was 5 ± 58 arbitrary units.

Performance, Squad Size, and Player Availability

A 2-SD increase in squad size (10 players) was associated with a 6-unit increase in performance (90% CI = −2, 14; *P* = .34), and a 2-SD increase in player availability (14%) was associated with a 7-unit increase in performance (90% CI = −1, 15; *P* = .16). These findings indicated that a larger squad size and greater percentage availability were associated with improved performance; however, both were considered not different or likely trivial and were excluded from further analysis.

Injury Burden and Performance

The relationship between injury burden and performance displayed nonlinear tendencies (*P* = .09), so injury burden was split into quartiles for analysis (*low*, 0–12 days; *low-moderate*, 13–47 days; *high-moderate*, 48–117 days; and *high*, 118–869 days). Moving from a low to a high injury burden was associated with an 18-unit decrease in performance (90% CI = 5, 31) and was deemed greater than the smallest worthwhile change and likely harmful (*P* = .01; Figure 1). When moving from the low to low-moderate or high-moderate category, only very likely trivial 7-unit (90% CI = −6, 20) and 9-unit (90% CI = −4, 23) changes in performance were seen.

Training Load and Performance

Average weekly load and the ACWR displayed only linear tendencies (*P* = .24) and were analyzed per 2-SD change. The smoothed chronic load displayed nonlinear characteristics and was analyzed in quartiles (Figure 2). A 2-SD change in average load and the ACWR were associated with a likely trivial 6-unit increase (90% CI = −7, 20) and 3-unit decrease (90% CI = −11, 18), respectively, in performance. Moves from a low to low-
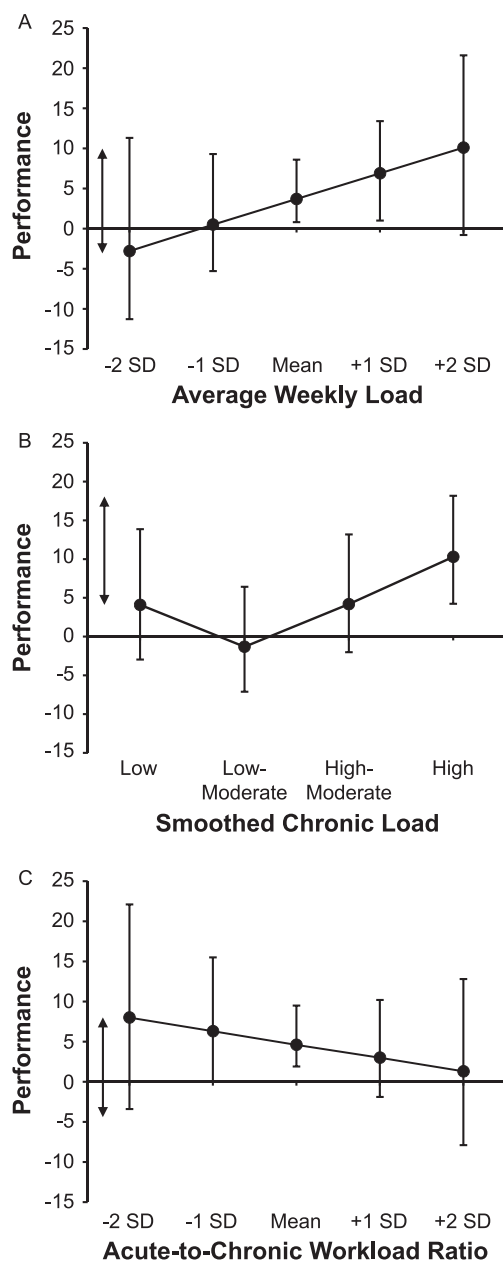
Figure 2. Association between training load and performance for A, average weekly (acute) load; B, smoothed chronic load; and C, acute:chronic workload ratio with 90% confidence intervals. The arrow indicates the smallest worthwhile change[6] in performance = 11.7 units. It is anchored on the first value on each graph and points either above (A and B) or below (C) that point in the same direction of the relationship.

Figure 3. Association between training load and injury burden for A, average weekly (acute) load; B, smoothed chronic load; and C, acute:chronic workload ratio with 90% confidence intervals. The arrow indicates the smallest worthwhile change[6] in injury burden = 21.3 units. It is anchored on the first value on each graph and points above that point in the same direction of the relationship. [a] Clear difference between reference group and group of interest.

moderate, a low to high-moderate, and a low to high category of smoothed chronic load were associated with a likely trivial 5-unit decrease (90% CI = −18, 8), 0.1-unit increase (90% CI = −13, 13), and 6-unit increase (90% CI = −7, 19), respectively, in performance.

Training Load and Injury Burden

Average weekly load and smoothed chronic load displayed no nonlinear properties (P = .73 and .36, respectively) and were analyzed per 2-SD change, whereas a nonlinear relationship was present in the ACWR variable and analyzed using the same quartiles (P < .01). Changes
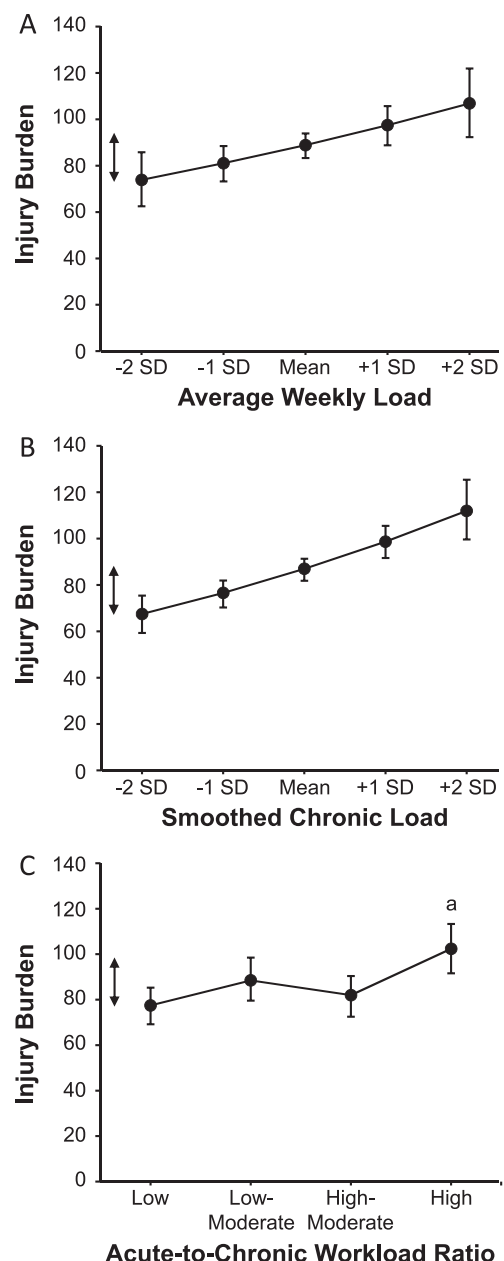
in the average weekly and smoothed chronic load variables were associated only with likely trivial 15-unit (90% CI = −2, 32) and possibly trivial 20-unit (90% CI = −7, 2) changes in injury burden (Figure 3A and B). The ACWR variable demonstrated a possibly harmful 25-unit increase (90% CI = 4, 46; P = .02) in injury burden (Figure 3C).

Training Load and Performance at Different Levels of Injury Burden

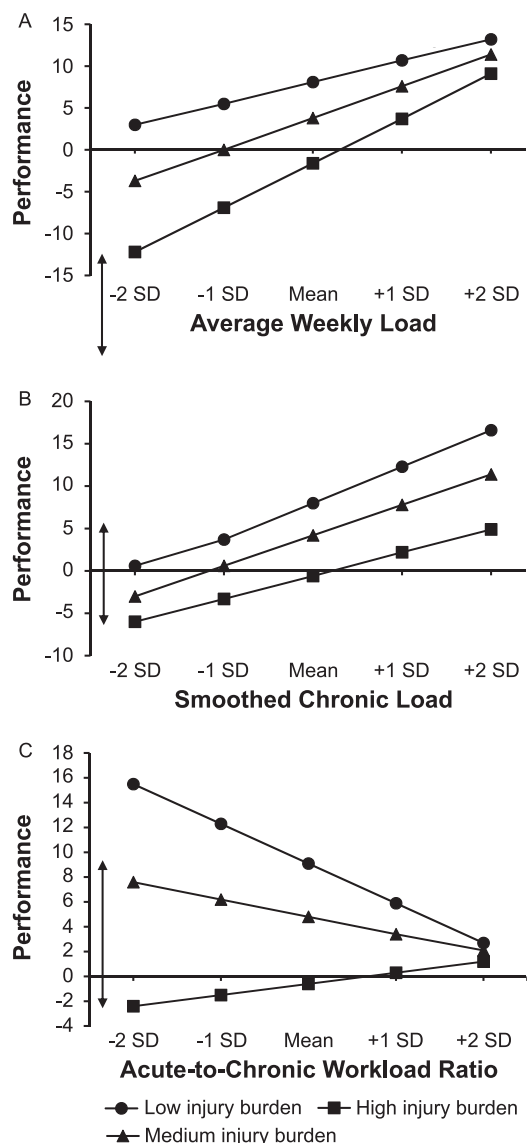A clear main effect of injury burden on performance was observed, with lower levels of injury burden associated

Figure 4. Association between training load and performance at 3 levels of injury burden for A, average weekly (acute) load; B, smoothed chronic load; and, C, acute:chronic workload ratio. The arrow indicates the smallest worthwhile change[6] in performance = 11.7 units. It is anchored on the first value on each graph and points either below (A) or above (B and C) that point in the same direction of the relationship.

with improved performance was observed; yet no clear interaction effect between training load and injury (Figure 4). Despite no clear interactions, visual inspection of Figure 4C suggests an interaction among the 3 levels of injury burden and the ACWR load variable.

DISCUSSION

This study provides an overview of the associations among team average training load, injury burden, and performance in rugby union. Injury burden was negatively associated with performance, whereas training load measures (average weekly, smoothed chronic, and ACWR) displayed only trivial associations with performance. Of the training load measures assessed, only the ACWR variable was associated with injury burden. When accounting for

injury burden, we noted no interaction effect with training load on performance was seen, meaning that the effect of load on performance did not depend on the level of injury burden. Despite this, across all 3 measures of training load, the lowest injury burden category was associated with the highest level of performance.

To understand the role of squad size and player availability in rugby union, we assessed these measures to identify whether either would contribute to an enhanced likelihood of success. The change in performance (6 performance units) associated with a 2-SD change in squad size did not reach the threshold for the smallest worthwhile change, indicating that increasing squad size by 10 players would not be associated with a meaningful change in performance if player management were to remain unchanged. Similarly, the change in performance associated with a 2-SD change in player availability meant that a 14% improvement in availability did not lead to a meaningful change in performance (7-unit increase). However, this analysis did not account for the players in this study who sustained injuries and their relative importance within the squad, which is likely to influence the effect of player availability on performance.[12] Furthermore, in the data representing player availability, a number of athletes who spent most of the time available for selection were included because they are rarely involved in top-level fixtures and consequently do not experience exposure to higher injury risk during match play. This was exemplified by Quarrie et al,[27] who reported that 40% of all Premiership players played <548 minutes (7 games) per season. Further analysis in this study was performed on the players involved in fixtures on a weekly basis, which may represent a better assessment of high-quality player availability than player availability across the squad as a whole.

A negative association between injury burden and team success has been shown in rugby union,[11] as well as several other sports.[7] According to Williams et al,[11] the injury and performance metrics were injury burden (injury incidence × mean severity), league points tally, and season average Eurorugby Club Ranking. They found clear negative associations between injury burden and team success on a seasonal basis, and our study supported this finding on a weekly basis: a high injury burden was associated with a likely harmful 18-unit decrease in performance (Figure 1). To contextualize what this may mean for performance in Premiership or European competitions, minimizing the injury burden (to <12 days) during a week increases the likelihood of performance by 18 units, which for a challenging fixture could be the difference between winning or losing the game (eg, going from a 1-point loss to a 2-point win in a match with an MDI = 9). This change of 18 units could also represent the difference in a team achieving or not achieving a bonus point in a game (eg, scoring a try in the last minutes of a game with an MDI = 2.5). Although this 18-unit change in performance may not always be important in the context of that game, these changes could result in 3 extra league points at the end of the season for a team, which has been reported as a meaningful change in points tally as the difference between playoff (fourth versus fifth) positions and European qualification (sixth versus seventh) positions.[11] This result supports the benefit of minimizing injury risk.

Changes in the acute, chronic, and ACWR variables demonstrated trivial associations with performance. These findings do not support the work of Lazarus et al,[6] who determined that performance was at the highest level when near the mean or approximately 1 SD less than the mean. The trend toward a lower-than-average load value contributing to a greater performance score was seen with the ACWR measure; yet the opposite occurred with the average weekly load measure, whereby a greater-than-average value was associated with a higher performance score. However, these findings were not clearly beneficial. The lack of clear findings may have been due to the lack of sensitivity of the performance and load measures. The absence of consistent associations between training load and performance prevents us from offering any meaningful recommendations for practice, reflecting the conclusions of Fox et al[16] in their recent systematic review across team sports, in which they also identified inconsistencies in this relationship.

When we assessed training load and injury burden, 2-SD changes in average weekly and smoothed chronic loads were associated with only trivial changes in injury burden. Despite this, a high ACWR was associated with a possibly harmful 25-unit increase in injury burden ($P = .02$). This result appeared to support the data of researchers in rugby union,[28] soccer,[29] cricket,[30] and several other sports[14] who showed that large spikes in load were associated with increased injury risk. Overall, the analysis of training load and injury burden indicated that, when we considered team averages, the ACWR metric had a greater effect than either average weekly or smoothed chronic load in isolation. Furthermore, increasing ACWR values showed negative, yet trivial, findings for performance, with high ACWR values representing the lowest performance level. Although these findings are unclear, they suggested that, for both minimizing injury burden and increasing the likelihood of team success, managing players to avoid large rises in the overall team average ACWR may be important. Of the 3 measures captured in this study, load was the one that can be directly modified by medical and conditioning staffs of clubs, so processes to monitor the load exposure of the squad are vital to ensuring that prolonged periods of high ACWR are minimized. In addition, this result based on group data should be assessed on an individual basis by practitioners because it is highly likely that individual responses to load will be apparent.

This study is one of the first to consider the influence of training load on both performance and injury burden simultaneously, and as such, the analysis of the effect of the 3 training load variables on performance score at 3 levels of injury burden was completed (Figure 4). As expected, when each of the 3 training load measures was evaluated, the lowest level of injury burden displayed the highest performance outcome in all cases, whereas the highest injury burden displayed the lowest performance value. Even though no interaction effect was present, when using the ACWR training load variable, visual inspection of the different slopes associated with each injury burden level suggested that with more sensitive measures of load, performance, and injury, the effect of load on performance may be moderated by injury burden.

One of the major difficulties associated with this type of research is the ability to define *performance*. One of the limitations of this study may have been the lack of

sensitivity of the performance marker used. Although MDIs have previously been used,[20] this metric and the weekly points difference have not previously been used together as a performance measure. Also, exclusion of 3 of the dynamic factors suggested in the original research[20] may have decreased the sensitivity of the performance measure. Without the level of performance indicators used by Bennett et al,[31] the MDI was used to account for both the difficulty of the game and the outcome. Limitations associated with the performance measure may explain the lack of a relationship between training load and performance, and improvements to these measures may improve the association strength between the variables. Another limitation with potential for improvement in further work is the individualization of the training load and injury data. Other avenues for future research include distinguishing between match preparation burden and match burden itself to identify whether the injury burden from the buildup to a game is more disruptive than the injury burden from the game itself.

High ACWR had a possibly harmful effect on injury burden but a trivial effect on performance and so may offer a method for managing risk while maintaining team-level performance. This study focused on team average data, so these data comprised a spread of ACWR values in individuals. In practical terms, altering these weekly load values requires an individualized approach to training for each athlete to ensure that his or her needs are met.

CONCLUSIONS

This study demonstrated a clear association between training load and injury risk at the team level and supported the well-established link between injury and performance. Although associations between training load and performance were not clear, this study outlined need to build measures of performance into research examining training load and injury.

ACKNOWLEDGMENTS

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