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The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players

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ABSTRACT

Aim Investigate whether acute workload (1 week total distance) and chronic workload (4-week average acute workload) predict injury in elite rugby league players.

Methods Data were collected from 53 elite players over two rugby league seasons. The 'acute:chronic workload ratio' was calculated by dividing acute workload by chronic workload. A value of greater than 1 represented an acute workload greater than chronic workload. All workload data were classified into discrete ranges by z-scores.

Results Compared with all other ratios, a very-high acute:chronic workload ratio (≥ 2.11) demonstrated the greatest risk of injury in the current week (16.7% injury risk) and subsequent week (11.8% injury risk). High chronic workload (>16 095 m) combined with a very-high 2-week average acute:chronic workload ratio (≥ 1.54) was associated with the greatest risk of injury (28.6% injury risk). High chronic workload combined with a moderate workload ratio (1.02–1.18) had a smaller risk of injury than low chronic workload combined with several workload ratios (relative risk range from 0.3 to 0.7×/÷1.4 to 4.4; likelihood range=88–94%, likely). Considering acute and chronic workloads in isolation (ie, not as ratios) did not consistently predict injury risk.

Conclusions Higher workloads can have either positive or negative influences on injury risk in elite rugby league players. Specifically, compared with players who have a low chronic workload, players with a high chronic workload are *more resistant to injury* with moderate-low through moderate-high (0.85–1.35) acute:chronic workload ratios and *less resistant to injury* when subjected to 'spikes' in acute workload, that is, very-high acute:chronic workload ratios ~1.5.

INTRODUCTION

Injuries commonly occur in team sports[1–4] and negatively influence team success in domestic[5 6] and continental[7] competitions. High training and match-play workloads increase injury likelihood in team sports.[8 9] However, physical attributes such as higher aerobic capacity, prolonged high-intensity running ability, and greater body mass index, improve with increases in workload[10–13] and decrease injury likelihood.[14–16] Consequently, the optimal workload that improves fitness, without increasing the likelihood of injury is of great importance to coaches and clinicians.[17]

Workload-injury investigations in team sports typically quantify workload in absolute terms (eg, the workload performed in a week vs injury).[8 9 18]

However, *workload-performance* investigations have examined absolute workload performed in 1 week (referred to as acute workload) relative to 4-week chronic workload (ie, 4-week average acute workload).[19–21] The logic behind this comparison of workloads is the provision of a workload index, which provides an indication of whether the athlete's recent acute workload is greater, less than or equal to the workload that the athlete has been prepared for during the preceding chronic period. We refer to this method as the acute:chronic workload ratio.

Using the acute:chronic workload ratio concept, we demonstrated that the risk of cricket fast bowlers sustaining an injury increased threefold when acute bowling workloads were double chronic bowling workloads (ie, an acute:chronic workload ratio ≥ 2).[22] Also, higher chronic workload protected against injury. However, the physical demands of cricket differ from many high-intensity, intermittent football codes.[23] The acute:chronic workload ratio, which compares the size of acute workload relative to chronic workload has not been used to investigate the workload-injury relationship in a team sport other than cricket. Furthermore, no study has investigated the influence of changes in acute workload when players have been exposed to either high or low chronic workloads.

Global positioning systems (GPS) data provides a major advancement in the ability of scientists, coaches and clinicians to monitor individual athlete's workloads even in the team sport setting.[24–31] To our knowledge, no research has investigated if the comparison of acute and chronic workloads derived from GPS is associated with injury in either the current week, subsequent week, or as an average over 2 weeks, in elite team sport athletes.[18 32] Therefore, we investigated whether distance covered, measured by GPS and calculated as an acute:chronic workload ratio predicted injury in elite rugby league players.

METHODS

Participants

Fifty-three players (mean±SD age, 23.4±3.5 years) from one elite rugby league club participated in this study over two Australian National Rugby League seasons. Of the two seasons, 20 (38%) participants competed in both seasons and 33 (62%) participants competed in one season—equating to a total of 73 individual seasons of rugby league. Each season consisted of a 13-week pre-season period

followed by 27 weeks of competition. All participants provided written consent and received a clear explanation of the study. All experimental procedures were approved by the Institutional Review Board for Human Investigation.

Quantifying workload

Workload was defined as absolute total distance (m) covered during all field training sessions and matches and was measured via GPS (GPSports, SPI-HPU 5 Hz (interpolated 15 Hz), Canberra, Australia). The GPS equipment used in this study is accurate and reliable for measuring total distance covered.[33 34] This equipment presents challenges when measuring accelerations,[35] decelerations,[35] high-speed running[34 36] and collisions.[37] Therefore, total distance was the only variable included in this study.[38]

Our analysis included all field training sessions and matches throughout the 2013 and 2014 seasons. A total of 8177 individual files consisting of 6777 training session files and 1400 match files were used.

Definition of injury

Injury records were updated and maintained by the club's senior physiotherapist. An injury was defined as any time-loss injury that resulted in a player being unable to complete full training or missing match time.[39] Thus, our definition of injury included both 'acute' and 'overuse' injuries.

Data analysis

Data were categorised into weekly blocks from Monday to Sunday. One-week total distance covered represented acute workload. Chronic workload was calculated as the 4-week rolling average acute workload. Skewness and kurtosis indices were explored using SPSS and data demonstrated normal distribution. The acute:chronic workload ratio was calculated by dividing the acute workload by the chronic workload—providing the relative size of acute workload compared with chronic workload. A value of greater than 1 represents an acute workload greater than chronic workload and vice versa.

Workload classifications consisting of very-low through very-high were created according to z-scores.[40 41] These classifications are displayed in table 1. Absolute workload and relative workload ratios are different variables and may display a different amount of variation. This could explain the asymmetrical z-scores for very-low through very-high acute:chronic workload ratios.

Training weeks in which players performed a chronic workload below a z-score of -2 (very-low) were removed from the analysis of acute:chronic workload ratios.[22] This removal

Table 1 Workload classifications and boundaries for: (A) acute workloads, (B) chronic workloads, (C) acute:chronic workload ratios overall, and (D) acute:chronic workload ratios combined with low (<16 095 m), and high (>16 095 m) chronic workloads

(A) Acute workload	z-Score	Current and Subsequent week (m)	Two-week average (m)
Very-low	≤−2.00	≤3268	≤5020
Low	−1.99 to −1.00	3269–9624	5021–10 351
Moderate-low	−0.99 to −0.01	9625–16 000	10 352–15 668
Moderate-high	0.00 to 0.99	16 001–22 364	15 669–20 966
High	1.00 to 1.99	22 365–28 797	20 967–26 265
Very-high	≥2.00	≥28 798	≥26 266
(B) Chronic workload			
Very-low	≤−2.00	≤6955	≤6675
Low	−1.99 to −1.00	6956–11 343	6676–11 074
Moderate-low	−0.99 to −0.01	11 343–15 729	11 075 –15 526
Moderate-high	0.00 to 0.99	15 730–20 116	15 527 –19 995
High	1.00 to 1.99	20 117–24 503	19 996 –24 449
Very-high	≥2.00	≥24 504	≥24 450
(C) Acute:chronic workload ratio		**Current and Subsequent week**	**Two-week average**
Very-low	≤−2.00	≤0.30	≤0.45
Low	−1.99 to −1.00	0.31–0.66	0.46–0.74
Moderate-low	−0.99 to −0.01	0.67–1.02	0.75–1.01
Moderate	0.00 to 0.99	1.03–1.38	1.02–1.30
Moderate-high	1.00 to 1.99	1.39–1.74	1.31–1.58
High	2.00 to 2.99	1.75–2.10	1.59–1.87
Very-high	≥3.00	≥2.11	≥1.88
(D) Acute:chronic workload ratio		**Combined with low chronic workload**	**Combined with high chronic workload**
Very-low	≤−2.00	≤0.30	≤0.66
Low	−1.99 to −1.00	0.31–0.66	0.67–0.84
Moderate-low	−0.99 to −0.01	0.67–1.02	0.85–1.01
Moderate	0.00 to 0.99	1.03–1.37	1.02–1.18
Moderate-high	1.00 to 1.99	1.38–1.74	1.19–1.35
High	2.00 to 2.99	1.75–2.16	1.36–1.53
Very-high	≥3.00	≥2.17	≥1.54

equated to 3.8% of the data set (86 of 2292 individual training weeks). This was performed so that a small increase in acute workload at very-low chronic workload would not be considered. That is, a player who had been subjected to an acute workload of 3000 m, whilst having a chronic workload of 1000 m, would have a very-low (2000 m) absolute increase in workload but this would represent a very-high acute:chronic workload ratio.[22] These very low workloads remained in the data set for the independent comparison of injury with absolute workloads.

The second aim of the present study was to investigate injury risk relative to the acute:chronic workload ratio when chronic workload is high, and when chronic workload is low. As such, chronic workloads were dichotomised by the median score (16 095 m) and injury-workload relationships between acute:chronic workload ratios combined with high, and low chronic workloads were calculated.

Statistical analysis

The risk of injury±90% CI was calculated for the week that the workload occurred (current week), the following week (subsequent week), and for the average workload over the current and previous week (2-week average). Injury risks were calculated as the number of injuries sustained relative to the number of exposures to each workload classification.[22 38] Null-hypothesis testing was conducted using a binary logistic regression model with injury/no injury as the dependent variable. Acute workload, chronic workload, and acute:chronic workload ratios were independently modelled as predictor variables. Relative risk (RR)×/÷90% CI were calculated to determine which workload variables increased (RR >1) or decreased (RR<1) the risk of injury.[38] Owing to the inability of RR to provide ±90% CI, the square root of (upper CI/lower CI) provided a ×/÷90% CI.[42]

Results of clinical and practical significance can be overlooked due to non-significant (p>0.05) null-hypothesis tests, which fail to adequately deal with the real-world importance of an effect.[43 44] As such, the p value derived from binary logistic regression and the value of the RR between groups were used to calculate the probabilities that the true effect was harmful, trivial and beneficial.[42] These values were reported in quantitative and qualitative terms according to the following: ≥5%, unlikely; ≥25%, possibly; ≥75%, likely; ≥95%, very likely.[43 44] Practical significance occurred when the probability that the true effect was either harmful or beneficial was ≥75%, likely.[44]

RESULTS

A total of 205 injuries (20.2/1000 h) were recorded. The most common sites of injury were the thigh (23.4%), knee (13.2%), and ankle (11.7%).

Acute, and chronic workloads

In the current week, a very-high acute workload (≥28 798 m) was associated with an increased risk of injury, compared with all other acute workloads (RR range from 1.9 to 13.9×/÷1.9 to 2.2; likelihood range=86–98%, likely–very likely), table 2. There were no differences in injury risk among any chronic workload categories (RR range from 0.6 to 1.3×/÷1.0 to 15.8; likelihood range=16–63%, unlikely–possibly), table 3.

Acute:chronic workload ratio

In the current week, a very-high acute:chronic workload ratio (≥2.11) was associated with an injury risk that was: (1) 6.9 times greater than a very-low ratio of ≤0.30 (RR=6.9×/÷1.7; likelihood=98%, very likely), (2) 3.4 times greater than a low ratio of 0.31–0.66 (RR=3.4×/÷2.0; likelihood=97%, very

likely), (3) 2.3 times greater than a moderate ratio of 1.03–1.38 (RR=2.3×/÷3.4; likelihood=91%, likely), and (4) double that of a high ratio of 1.75–2.10 (RR=2.0×/÷17.2; likelihood=77%, likely), table 4.

A very-high 2-week average acute:chronic workload ratio (≥1.88) was associated with a risk of injury that was: (1) 2.2 times greater than a low ratio of 0.46–0.74 (RR=2.2×/÷4.9; likelihood=87%, likely), (2) 1.9 times greater than a moderate-low ratio of 0.75–1.01 (RR=1.9×/÷5.5; likelihood=83%, likely), and (3) 2.4 times greater than a moderate ratio of 1.02–1.30 (RR=2.4×/÷3.0; likelihood=92%, likely), table 4. In the subsequent week, a very-high acute:chronic workload ratio demonstrated a 10-fold increase in injury risk compared with a very-low ratio (RR=9.8×/÷3.6; likelihood=97%, very likely), table 4.

A high chronic workload (>16 095 m) combined with a very-high two-week average acute:chronic workload ratio (≥1.54) was associated with a greater risk of injury than a high chronic workload combined with the following workload ratios: low (0.67–0.84 (RR=3.0×/÷4.3; likelihood=92%, likely)), moderate-low (0.85–1.02 (RR=3.8×/÷2.3; likelihood=96%, very likely)), moderate (1.02–1.18 (RR=4.6×/÷1.8; likelihood=98%, very likely)), moderate-high (1.19–1.35

Table 2 Relationships between acute workload and the risk of injury (±90% CI) during the current week, subsequent week, and with 2-week average acute workloads

Risk of injury (%)±90% CI			
Acute workload	Current week	Subsequent week	Two-week average
Very-low	1.5±2.4*	8.0±5.2	2.2±2.5†
Low	6.0±2.2	10.3±2.8	5.8±2.3‡
Moderate-low	9.9±1.9	6.9±1.7	8.8±1.8
Moderate-high	8.4±1.5	11.0±1.8	9.2±1.6
High	8.0±2.3	6.9±2.2§	8.0±2.4
Very-high	18.8±16.1¶	0.0±0.0	6.3±10.0

*Very likely (≥95%) decreased risk of injury than moderate-low through very-high in the current week.
†Likely (≥75%) decreased risk of injury than 2-week average categories moderate-low through very-high.
‡Likely (≥75%) decreased risk of injury than 2-week average acute workload categories moderate-low and moderate-high.
§Very likely (≥95%) and likely (≥75%) decreased risk of injury in the subsequent week compared with moderate-high and low.
¶Very likely (≥95%) greater injury risk in the current week than very-low and low, and likely (≥75%) greater injury risk in the current week than moderate-low through high.

Table 3 Relationships between chronic workload and the risk of injury (±90% CI) during the current week, subsequent week, and with 2-week average chronic workloads

Risk of injury (%)±90% CI			
Chronic workload	Current week	Subsequent week	Two-week average
Very-low	4.7±3.7	8.9±5.3	6.6±4.7
Low	8.6±3.2	8.8±3.3	8.1±3.1
Moderate-low	10.8±1.9	9.2±1.8	9.4±1.8
Moderate-high	7.8±1.6	8.7±1.7	8.7±1.6
High	8.5±2.6	7.4±2.4	8.5±2.5
Very-high	0.0±0.0	9.1±14.3	0.0±0.0

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Table 4 Relationships between acute:chronic workload ratios and the risk of injury (±90% CI) in the current and subsequent weeks, and with 2-week average acute:chronic workload ratios

Risk of injury (%)±90% CI

Acute:chronic workload ratio	Current week	Subsequent week	Two-week average
Very-low	2.4±2.8*	1.2±2.0*	0.0±0.0
Low	5.0±2.5	8.9±3.4	7.6±3.1
Moderate-low	10.2±1.9	7.8±1.6	8.9±1.6
Moderate	7.2±1.5	7.8±1.6	6.9±1.6
Moderate-high	10.9±3.6	10.5±3.7	13.0±4.3†
High	8.3±7.6	8.1±7.4	11.8±7.4‡
Very-high	16.7±14.4§	11.8±12.9	16.7±14.4¶

*Very likely (≥95%) and likely (≥75%) decreased risk of injury in the current and subsequent week than all other acute:chronic workload ratios.
†Very likely (≥95%) and likely (≥75%) increased risk of injury compared with low, moderate-low and moderate 2-week average.
‡Likely (≥75%) greater risk of injury than a moderate 2-week average.
§Very likely (≥95%) greater risk of injury than low, and very-low in the current week. Likely (≥75%) greater injury risk than moderate and high in the current week.
¶Likely (≥75%) greater risk of injury than low, moderate-low and moderate 2-week average.

(RR=4.0×/÷2.6; likelihood=96%, likely)), and high (1.36–1.53 (RR=2.4×/÷16.3; likelihood=82%, likely)), table 5.

Table 6 displays the differences in injury risk among acute:chronic workload ratios combined with high chronic workloads, and low chronic workloads.

A low chronic workload (<16 095 m) combined with a very-high two-week average acute:chronic workload ratio (≥2.17) was associated with greater injury risks than a low chronic workload combined with the following workload ratios: low (0.31–0.66 (RR=2.3×/÷9.8; likelihood=84%, likely)), moderate-low (0.67–1.02 (RR=1.8×/÷13.5; likelihood=75%, likely)), moderate (1.03–1.37 (RR=2.0×/÷11.7; likelihood=79%, likely)), and high (1.75–2.16 (RR=3.1×/÷55.5; likelihood=81%, likely)), table 5.

DISCUSSION

In this first study to investigate injury risk relative to the comparison of GPS derived acute and chronic workloads, we found

Table 5 Relationships among risk of injury (±90% CI) and 2-week average acute:chronic workload ratios combined with low (<16 095 m) chronic workload, and high (>16 095 m) chronic workload

Risk of injury (%)±90% CI

Acute:chronic workload ratio	Combined with low chronic workload	Combined with high chronic workload
Very-low	0.0±0.0	0.0±0.0
Low	7.8±4.1	9.6±4.1
Moderate-low	10.0±2.5	7.5±2.2
Moderate	9.3±2.6	6.2±2.2
Moderate-high	11.0±4.9	7.1±4.0
High	5.9±7.3	12.0±10.7
Very-high	18.2±14.9*	28.6±18.1†

*Likely (≥75%) greater risk of injury than a low chronic workload combined with a low, moderate-low, moderate, and high.
†Very likely (≥95%) greater risk of injury than high chronic workload combined with moderate-low, moderate, and moderate-high.

that a ratio of acute and chronic workloads predicted injury in elite rugby league players. This ratio indicates how the player's recent acute workload compares with the work completed during the preceding chronic period. We refer to this model as the acute:chronic workload ratio.

The value of our model is represented firstly by a very-high acute:chronic workload ratio demonstrating a greater risk of injury than all other workload ratios in the current week, subsequent week, and 2-week average. Second, the relationships between injury risk and acute, and chronic workloads in isolation were less consistent. For example, a very high acute workload was associated with an increased injury risk in the current week, yet no injuries were sustained in the subsequent week, and no injury-workload relationships were observed between a very-high 2-week average acute workload and moderate-low to high 2-week average acute workloads. Furthermore, no injury-workload relationships were found among any isolated chronic workload categories. Collectively these findings demonstrate that the acute:chronic workload ratio is a greater predictor of injury than either acute or chronic workload in isolation.

The workload-injury paradox: higher chronic workload protects against injury when acute workload is similar to chronic workload.

A novel finding of this study was that a high chronic workload combined with moderate, and moderate-high workload ratios had a smaller risk of injury than a low chronic workload combined with several acute:chronic workload ratios. Others have demonstrated that rugby league players with greater aerobic capacity[14] and prolonged high-intensity running ability[15] have a decreased risk of injury. Potentially, players in the current study who achieved a higher chronic workload may have improved the physical attributes associated with decreased injury risk. Additionally, coaches and clinicians perceive excessive fatigue, and low levels of fitness to be important factors that increase injury risk in team sport athletes;[17] higher levels of fitness reduce post-match neuromuscular fatigue in rugby league players.[26] Furthermore, Banister et al[19–21] originally reported chronic and acute workloads as estimates of the relative comparison between fitness and fatigue. These authors did this by expressing 'fatigue' as the athlete's acute workload, whereas 'fitness' was expressed as chronic workload.[19–21] When considering our findings, players who were training at a moderate acute:chronic workload ratio had an acute workload (ie, 'fatigue') similar in size to their chronic workload (ie, 'fitness'). Therefore, it may be expected that a moderate acute:chronic workload ratio combined with a high chronic workload (ie, high 'fitness') was associated with a smaller risk of injury than a moderate acute:chronic workload ratio combined with a low chronic workload (ie, low 'fitness').

The greatest risk of injury in this study was displayed when a high chronic workload was combined with a very-high acute:chronic workload ratio. Collectively, our findings highlight that compared with players that have a low chronic workload, players with a high chronic workload are: (1) more resistant to injury with moderate-low to moderate-high acute:chronic workload ratios and (2) less resistant to injury when exposed to large spikes in workload, that is, very-high acute:chronic workload ratios ~1.5.

Our results are consistent with findings from cricket.[22] In the present study, when players were subjected to a workload (ie, acute workload) that was classified as ~twofold greater than the workload in which they were accustomed (ie, chronic workload), up to a 10-fold increase in the risk of injury occurred. These findings may seem intuitive and unsurprising to

Table 6 Relative risk (RRx/÷90% CI) of injury for high chronic workload (>16 095 m) combined with acute:chronic workload ratios (top row), compared with low chronic workload (<16 095 m) combined with acute:chronic workload ratios (left column)

Chronic workload/acute:chronic workload ratio	High/very-low RRx/÷90% CI	High/low RRx/÷90% CI	High/moderate-low RRx/÷90% CI	High/moderate RRx/÷90% CI	High/moderate-high RRx/÷90% CI	High/high RRx/÷90% CI	High/very-high RRx/÷90% CI
Low/Very-low	0.0x/÷>100	0.0x/÷>100	0.0x/÷>100	0.0x/÷>100	0.0x/÷>100	0.0x/÷>100	0.0x/÷>100
Low/Low	0.0x/÷>100	1.2x/÷6.7	1.0x/÷6.3	0.8x/÷5.6	0.9x/÷10.2	1.5x/÷14.9	3.7x/÷3.0*
Low/Moderate-low	0.0x/÷>100	1.0x/÷4.6	0.8x/÷1.9†	0.6x/÷1.4†	0.7x/÷3.8	1.2x/÷15.1	2.9x/÷4.0†
Low/Moderate	0.0x/÷>100	1.0x/÷4.8	0.8x/÷2.5	0.7x/÷1.8†	0.8x/÷4.8	1.3x/÷14.8	3.1x/÷3.5†
Low/Moderate-high	0.0x/÷>100	0.9x/÷6.2	0.7x/÷2.6†	0.6x/÷1.8†	0.6x/÷4.4†	1.1x/÷21.0	2.6x/÷6.2†
Low/High	0.0x/÷>100	1.6x/÷156.8	1.3x/÷24.4	1.1x/÷147.7	1.2x/÷163.2	2.0x/÷113.3	4.9x/÷13.4†
Low/Very-high	0.0x/÷>100	0.5x/÷14.8†	0.4x/÷6.7†	0.3x/÷4.4†	0.4x/÷8.1†	0.7x/÷49.7	1.6x/÷56.2

*RR very likely (≥95%) different.
†RR likely (≥75%) different.

practitioners. However this study provides a method of, and threshold values for modelling acute and chronic workloads to predict the relative risk and likelihood of injury in elite rugby league players. Furthermore, the goal of conditioning athletes is to optimise performance and minimise injury risk.[45] The acute: chronic workload ratio has been linked with improvements in performance in an individual sport,[19–21] and according to this study and others,[22] is linked with injury risk in team sports. Collectively, the aforementioned studies and the present findings endorse that monitoring acute:chronic workload ratios should be mainstream practice in elite sport. However, this is currently not the case.[45]

Another novel aspect of this study is the provision of threshold values that can be used to prescribe acute workload in order to obtain a high chronic workload. Specifically, acute workload can be increased to ~twofold of chronic workload without increasing injury risk in the current or subsequent week. However, if a very-high acute:chronic workload ratio (~2) is prescribed in the current week, or maintained as an average over 2 weeks, the risk of injury is likely greater than if acute workload were increased by a ratio less than 2. Additionally, acute:chronic workload ratios as an average over 2 weeks should be monitored in comparison to whether chronic workload is high or low. Our findings suggest that increasing acute workload as an average over 2 weeks by: (1) greater than ~1.5 relative to a high chronic workload, or (2) greater than ~2 relative to a low chronic workload, will result in an increased risk of injury in elite rugby league players.

This study has demonstrated useful associations between simple distance measures and injury risk in elite rugby league players. We suspect that more information may be available if accelerations, high-speed running, and collisions were accounted for, however, accurate and reliable analysis of these variables is not possible with the GPS equipment used in this study.[34–37] As such, accurate predictions of injury risk when using these variables would not be possible.[38] Further research may address this limitation and expand on the knowledge we have provided, by using GPS equipment (eg, Catapult, 10 Hz) that is capable of accurately and reliably measuring accelerations, high-speed running, and collisions.[34 36 46] Additionally, total distance covered has demonstrated a strong correlation (r=0.80) with session-RPE workload during high-intensity, intermittent team sport training.[47] Session-RPE workload also has a strong positive correlation with non-contact injury (r=0.82) and contact injury (r=0.80) in rugby league.[48] Session-RPE workload has been used to model acute:chronic workload ratios, which were associated with injury in elite cricket fast bowlers.[22] These studies collectively suggest that although total distance does not incorporate all aspects of training, it is an appropriate measure of workload.

Although the findings of this study demonstrate that very-low, and low absolute workloads are associated with decreased injury risk, we are tentative to recommend that players are consistently exposed to these workloads. Rugby league players can be required to cover ~1140 m during a 10 min period of match-play,[30 31] and 9561 m in a full 80 min match.[27] Therefore, very-low (~2500 m) and low (~6000 m) weekly workloads would likely result in players being underprepared for the physical demands of match-play, which may in turn increase the risk of injury.

Summary and conclusion

This is the first investigation of injury likelihoods relative to GPS derived acute and chronic workloads in elite rugby league

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players. Our findings demonstrate that the acute:chronic workload ratio provides a better prediction of injury than absolute workload in isolation. For the first time, we have investigated the influence of this workload ratio combined with high or low chronic workload—demonstrating that higher chronic workload can protect against injury when acute workload is similar to chronic workload. However, a high chronic workload, combined with large spikes in acute workload demonstrated the greatest risk of injury in this study. Our results establish that the ratio of acute workload to chronic workload should be monitored during the current week and as an average over 2 weeks relative to either a high, or low chronic workload. Finally, the findings of this study demonstrate that monitoring the comparison of acute and chronic workloads should be mainstream practice in elite sport.

What are the findings?

- ▶ The acute:chronic workload ratio is a greater predictor of injury than either acute or chronic workload separately.
- ▶ Compared with a low chronic workload, rugby league players with a high chronic workload are:
  - – More resistant to injury with moderate-low to moderate high acute:chronic workload ratios.
  - – Less resistant to injury with a very-high acute:chronic workload ratio.
- ▶ The acute:chronic workload ratio in the current week, subsequent week, and as an average over 2 weeks, is associated with increased injury risk in elite rugby league players.

How might it impact clinical practice in the future?

- ▶ Threshold values for modelling acute and chronic workloads to predict the relative risk and likelihood of sustaining an injury in elite rugby league players can be used in clinical practice.
- ▶ Total distance measured via global positioning systems can be modelled to predict injury risk.
- ▶ Clinical practice in team sports should incorporate monitoring of acute:chronic workload ratios.
- ▶ The size of an athlete's acute workload in relation to chronic workload should be monitored in the current week, and as an average over 2 weeks in comparison to either a high, or low chronic workload.

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The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players

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