Low chronic workload and the acute:chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players

Billy T Hulin,[1,2] Tim J Gabbett,[3,4] Peter Caputi,[5] Daniel W Lawson,[6] John A Sampson[1]

[1]Centre for Human and Applied Physiology, School of Medicine, University of Wollongong, Wollongong, New South Wales, Australia
[2]Football Department, St. George Illawarra Dragons Rugby League Football Club, Wollongong, New South Wales, Australia
[3]School of Exercise Science, Australian Catholic University, Brisbane, Queensland, Australia
[4]School of Human Movement Studies, University of Queensland, Brisbane, Queensland, Australia
[5]School of Psychology, University of Wollongong, Wollongong, New South Wales, Australia
[6]Baimed Physiotherapy and Sports Injury Clinic, Wollongong, New South Wales, Australia

Correspondence to Billy T Hulin, Football Department, St. George Illawarra Dragons RLFC, 1/5 Burelli Street, Wollongong, NSW 2500, Australia; billyhulin@hotmail.com

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ABSTRACT

Background Between-match recovery time, and acute and chronic workloads likely affect subsequent match-injury risk in elite rugby league players.

Methods Workloads of 28 players throughout two seasons were calculated during short (<7 days), and long (≥7 days) between-match recovery times. 'Acute' workloads (1 week) greater than 'chronic' workloads (4-week rolling average acute workload) resulted in acute:chronic workload ratios above 1.

Results No difference was found between the match-injury risk of short and long between-match recovery periods (7.5±2.5% vs 6.8±2.5%). When players had a short recovery between matches, high chronic workloads (18.9–22.0 km) were associated with a smaller risk of match injury than chronic workloads <18.9 km (relative risk (RR) range 0.27–0.32 (CI 0.08 to 0.92); likelihood range 90–95%, likely). Players who had shorter recovery and acute:chronic workload ratios ≥1.6, were 3.4–5.8 times likely to sustain a match injury than players with lower acute:chronic workload ratios (RR range 3.41–5.80 (CI 1.17 to 19.2); likelihood range 96–99%, very likely). Acute:chronic workload ratios between 1.2 and 1.6 during short between-match recovery times demonstrated a greater risk of match injury than ratios between 1.0 and 1.2 (RR=2.88 (CI 0.97 to 8.55); likelihood=92%, likely).

Conclusions Contrary to the philosophy that high workloads and shorter recovery equate to increased injury risk, our data suggest that high and very-high chronic workloads may *protect* against match injury following shorter between-match recovery periods. Acute:chronic workload ratios ∼1.5 are associated with a greater risk of match injury than lower acute:chonic workload ratios. Importantly, workloads can be manipulated to decrease the match-injury risk associated with shorter recovery time between matches.

INTRODUCTION

The likelihood of sustaining an injury in team sport can be influenced in part by: (1) the workloads that athletes are subjected to,[1–3] or (2) the recovery time that is provided between matches.[4 5] Three to 5 days recovery is required for match-induced reductions in neuromuscular and endocrine function to return to prematch values in team sport athletes.[6 7] During the shortest between-match recovery times in rugby league (5 and 6 days), training and preparation between matches is congested and there is a greater incidence of injury than during longer between-match recovery times (7 or more days).[5] However, at least two studies failed to find any association between congested fixture periods and higher injury incidence in other team sports.[8 9]

The equivocal evidence in relation to shorter between-match recovery times and increased injury risk may be due to the fact that previous studies have not investigated player workloads between matches.[4 5 8 9] Higher workloads can occur during longer between-match recovery times[10] and higher workloads[1 3] or abrupt increases in workloads[2 3 11] can increase injury risk. However, no study has investigated the combined influence of workloads and between-match recovery time on the risk of subsequent match injury in elite team sport athletes.

Regardless of the recovery time between matches, higher acute (ie, 1 week) workloads are associated with winning more matches in an elite team sport.[12] However, when acute workload exceeded chronic workload (ie, 4-week average acute workload), resulting in an acute:chronic workload ratio greater than 1, the probability of losing matches increased.[12] Furthermore, Hulin *et al*[11] recently demonstrated that acute and chronic workloads can have both positive and negative influences on injury risk in elite rugby league players. When players had an acute:chronic workload ratio close to 1, higher chronic workloads were associated with a smaller risk of injury than lower chronic workloads. Conversely, a large spike in acute workload relative to chronic workload (ie, ratios of >1.5) resulted in a threefold to fivefold increase in injury risk.[2 11]

The effect of: (1) higher chronic workloads or (2) abrupt increases in acute workload, on the risk of sustaining a match injury following different between-match recovery times is currently unknown. Therefore, we modelled acute and chronic workloads with the risk of sustaining a match injury following short (5 and 6 days) and long (7, 8 and 9 days) between-match recovery times in elite rugby league players.

METHODS

Participants

Twenty-eight players (mean±SD; age, 24.8 ±3.4 years; height, 184.5±4.9 cm; body mass, 99.5±8.0 kg) from one elite rugby league club participated in this study over two Australian National Rugby League (NRL) seasons. This study was conducted over the competition phase of each season (2×27 weeks). Only players participating in first-team matches and completing workloads between those matches were included in the analysis. Players received a clear explanation of the study and written consent was obtained. Experimental procedures were approved by the Institutional Review Board for Human Investigation.

Injury definition

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.[11 13 14] Only injuries that were sustained in a match or reported subsequent to a match, prior to the next training session, were included in the combined analysis of workload and between-match recovery time.

Workload and between-match recovery time analysis

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 has demonstrated adequate accuracy and reliability for measuring total distance covered[15 16]; however, this equipment is not accurate or reliable when measuring changes in velocity,[15 17] high-speed running[15 18] and collisions.[19] Therefore, these variables were excluded from analysis. In the event that a player did not wear a GPS unit or the GPS unit failed to collect data (<1% of the dataset), the player was given either the average workload of that training session or their average match workload over the season.[20]

Between-match workloads were calculated as the total distance covered during all field training sessions and the following match. Data were categorised into between-match recovery times comparable with previous studies.[5 10] Specifically, these recovery times consisted of <7 days (5 and 6 days, also referred to as 'short') between matches, or ≥7 days (7, 8 and 9 days, also referred to as 'long') between matches. Chronic workloads and acute:chronic workload ratios were calculated in accordance with previous work.[2 11 21 22] Briefly, data from Monday to Sunday represented the acute workload, while the 4-week rolling average acute workload represented the chronic workload. An acute workload greater than chronic workload was indicated by an acute:chronic workload ratio greater than 1, and vice versa.[2 11 21 22]

Workload data for short, and long between-match recovery times were further categorised into very-low through very-high categories according to percentile rank. These categories are displayed in table 1. Injury–workload relationships were calculated among very-low through very-high between-match workloads, chronic workloads and acute:chronic workload ratios.

Statistical analysis

Match-injury risks were calculated as the total number of match injuries sustained relative to the total number of exposures to each workload classification.[2 11 23] Null hypothesis testing was conducted using a binary logistic regression model with injury/no injury as the dependent variable. Between-match workloads, chronic workloads and acute:chronic workload ratios were independently modelled as predictor variables. Relative risk (RR) and 90% CI (lower-upper) were calculated to determine which workload variables increased or decreased the risk of match injury.[23] A RR of greater or less than 1 implied an increased or decreased risk of injury, respectively.

Table 1 Description of between-match workloads, chronic workloads and acute:chronic workload ratios during short and long between-match recovery times

		Between-match recovery time	
	Percentile rank (%)	Short	Long
Between-match workload (km)			
Very-low	≤5	≤9.0	≤12.0
Low	≤25	9.1–12.5	12.1–16.2
Moderate-low	<50	12.6–15.5	16.3–18.8
Moderate-high	≥50	15.6–17.8	18.9–21.6
High	≥75	17.9–21.4	21.7–25.3
Very-high	≥95	≥21.5	≥25.4
Chronic workload (km)			
Very-low	≤5	≤10.5	≤11.4
Low	≤25	10.6–14.3	11.5–14.7
Moderate-low	<50	14.4–16.5	14.8–17.0
Moderate-high	≥50	16.6–18.8	17.1–20.0
High	≥75	18.9–22.0	20.1–23.0
Very-high	≥95	≥22.1	≥23.1
Acute:chronic workload ratio			
Very-low	≤5	≤0.66	≤0.80
Low	≤25	0.67–0.86	0.81–0.99
Moderate-low	<50	0.87–1.01	1.00–1.09
Moderate-high	≥50	1.02–1.22	1.10–1.20
High	≥75	1.23–1.61	1.21–1.49
Very-high	≥95	≥1.62	≥1.50

The influence of between-player heterogeneity on the number of injuries sustained was examined used a Poisson regression model. In this model, positional group (forwards=1, backs=2) was used as a factor, while age, body mass and height were used as covariates.

Statistical analysis was performed in a similar fashion to other investigations of acute and chronic workloads and injury risk.[11] The p value derived from binary logistic regression and the value of the RR between groups were entered into a customised spreadsheet, which calculates 90% CI and the probabilities that the true effect was harmful, trivial and beneficial.[24 25] These values were reported in quantitative and qualitative terms according to the following: ≥1%, very unlikely; ≥5%, unlikely; ≥25%, possibly; ≥75%, likely; ≥95%, very likely.[24–26] Practical significance occurred when the probability that the true effect was either harmful or beneficial was ≥75%, likely.[24]

RESULTS

There were 44 match, and 9 training injuries. No difference was found between the risk of match injury following short (injury risk=7.7±2.5%) and long (injury risk=6.8±2.5%) between-match recovery periods (figure 1). However, 8 of the 9 training injuries occurred when recovery time was <7 days (short).

The Poisson regression model did not demonstrate any relationship among the number of injuries sustained and positional group (p=0.303), age (p=0.325), height (p=0.221) or body mass (p=0.167).

Between-match workloads

Figure 2A depicts the risk of match injury with very-low through very-high between-match workloads during short, and long between-match recovery times. During short between-match recovery times, a high between-match workload (17.9–21.5 km) was associated with a risk of match-injury that was:

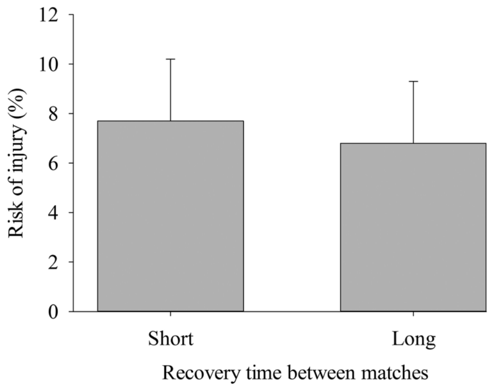

Figure 1 Risk of match injury±90% CI subsequent to short (5 and 6 days) or long (7, 8 and 9 days) recovery time between matches.

(1) 87% smaller than low between-match workloads (RR=0.13 (CI 0.02 to 0.67); likelihood=97%, very likely), (2) 82% lower than moderate-low between-match workloads (RR=0.18 (CI 0.03 to 0.95); likelihood=94%, likely), and (3) 85% lower than very-high between-match workloads (RR=0.15 (CI 0.02 to 1.03); likelihood=94%, likely).

Chronic workloads

No match injuries were sustained when players (n=17) had a very-high chronic workload (≥22.1 km) during short between-match recovery times. A high chronic workload (18.9–22.1 km) was associated with a risk of match injury that was: (1) 73% lower than a moderate-low chronic workload (RR=0.27 (CI 0.08 to 0.92); likelihood=95%, very likely), and (2) 68% lower than a low chronic workload (RR=0.32 (CI 0.08 to 1.22); likelihood=90%, likely; figure 2B). During short between-match recovery times, there was a linear trend for *lower* risk of subsequent match injury as chronic workload *increased* (figure 2B).

Acute:chronic workload ratios

A high acute:chronic workload ratio (1.23–1.61) during short between-match recovery times demonstrated a risk of match injury that was 2.88 times greater than a moderate-high acute:chronic workload ratio combined with short recovery between matches (RR=2.88 (CI 0.97 to 8.55); likelihood=92%, likely; figure 2C). The risk of match injury with a very-high acute:chronic workload ratio (≥1.62) combined with short recovery between matches was: (1) 5.80 times greater than a moderate-high acute:chronic workload ratio (RR=5.80 (CI 1.75 to 19.2); likelihood=99%, very likely), and (2) 3.41 times greater than a low acute:chronic workload ratio (RR=3.41 (CI 1.17 to 9.91); likelihood=96%, very likely; figure 2C).

Long between match recovery times, combined with a very-high acute:chronic workload ratio (≥1.50) displayed a risk of match injury that was 4.46 times greater than a moderate-high acute:chronic workload ratio (RR=4.46 (CI 0.91 to 21.91); likelihood=92%, likely; figure 2C).

With the exception of high acute:chronic workload ratios, when players' acute:chronic workload ratios were taken into account, the recovery time between matches did not have a significant independent effect on injury risk in the subsequent match (figure 2C).

DISCUSSION

This study investigated the combined influence of recovery time between matches and player workloads on subsequent match-injury risk in elite rugby league. We found no difference in the risk of match injury, subsequent to short (7.7% injury risk) or long (6.8% injury risk) recovery between matches. Our findings

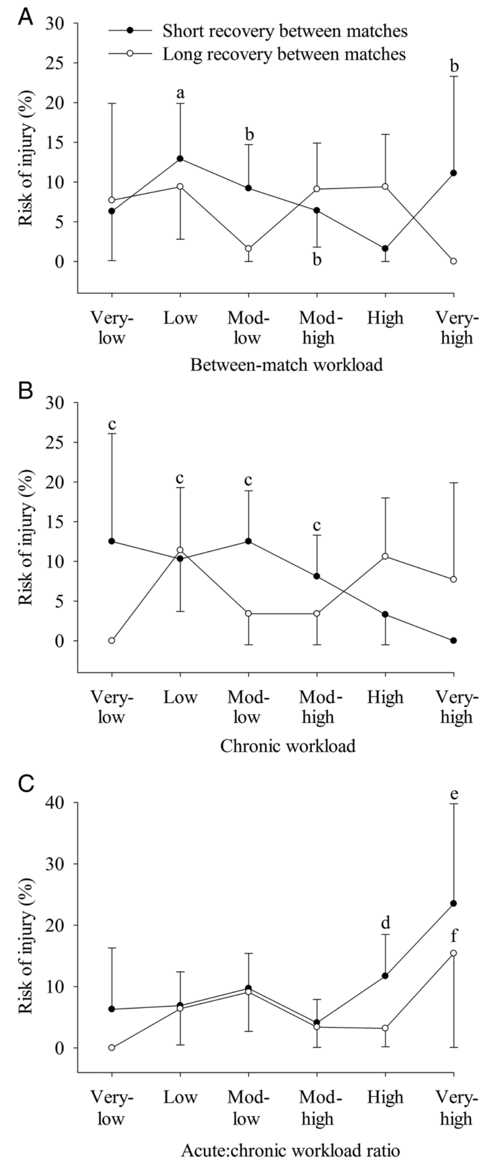

Figure 2 Risk of match injury±90% CI subsequent to short (5 and 6 days) or long (7, 8 and 9 days) recovery time between matches combined with between-match workloads (A), chronic workloads (B) and acute:chronic workload ratios (C). (a)Likely (≥75%) different from moderate-high between-match workload and very likely (≥95%) different from high between-match workload, during short between-match recovery times. (b)Likely (≥75%) different from high between-match workload during short between-match recovery time. (c)Likely (≥75%) different from high chronic workload during short between-match recovery time. (d) Likely (≥75%) different from low, and moderate-high acute:chronic workload ratios during short between-match recovery time and high acute:chronic workload ratio during long between-match recovery time. (e) Very likely (≥95%) different from low, and moderate-high acute:chronic workload ratio during either between-match recovery time, and high acute:chronic workload ratio during long between-match recovery time. Likely (≥75%) different from moderate-low acute:chronic workload ratio during either between-match recovery time and very-low and high acute:chronic workload ratio during short between match recovery time. (f) Likely (≥75%) different from low, and moderate-high acute:chronic workload ratio during either between-match recovery time. Likely (≥75%) different from high acute:chronic workload ratio during long between-match recovery time.

demonstrate that *higher* chronic workloads can *reduce* match injury risk following short between-match recovery times. However, increases in acute:chronic workload ratios are associated with a higher risk of match injury following short and long between-match recovery times.

The influence of workload and workload ratios on injury risk: does congestion matter?

We demonstrated that a controllable factor (workload) is associated with higher match-injury risk than non-modifiable between-match recovery time in isolation. Specifically, during short between-match recovery times, chronic workloads were associated with a linear trend for *lower* risk of injury as chronic workload *increased*. Additionally, high (1.2–1.6) and very-high (>1.6) acute:chronic workload ratios combined with a short recovery between matches were associated with a risk of match injury that was 2.8 and 5.8 times higher than an acute:chronic workload ratio between 1.0 and 1.2. Furthermore, with a long recovery between matches, very-high acute:chronic workload ratios (≥1.5) displayed a fourfold increase in match injury risk compared with ratios of 1.1–1.2. These findings demonstrate that *higher* workloads prior to short between-match recovery times can *decrease* injury risk, while sudden upgrades in workload will *increase* match-injury risk, regardless of the recovery time provided between matches.

In this study, the two greatest risks of match injury were observed when players had a very-high acute:chronic workload ratio combined with short (22% injury risk) or long (15% injury risk) recovery between matches. Additional match-injury risk factors in this study were when players had very-low to moderate-low chronic workloads during short between-match recovery times. Lower chronic workloads and sudden spikes in workload likely function together to increase the risk of match injury. That is, a high chronic workload may reduce the risk of injury due to the protection it provides against a very-high acute:chronic workload ratio. For example, chronic workloads of 19 and 12 km would be classed as high and low, respectively. Therefore, an acute workload greater than 20 km would result in moderate-high (ie, 1.1) and very-high (ie, 1.7) acute:chronic workload ratios for athletes with high and low chronic workloads, respectively. As such, higher chronic workloads may provide protection against a spike in acute workload, which was associated with the greatest risk of match injury in this study and overall injury in previous investigations.[2,11]

Low through very-high between-match workloads demonstrated a slightly 'V'-shaped relationship during short between-match recovery times. Specifically, high between-match workloads were associated with a lower risk of match injury than low through moderate-high and very-high between-match workloads (figure 2A). These findings demonstrate that some, but not excessive, workload is essential to decrease the risk of match injury when short recovery has been provided between matches. Additionally, no injuries were sustained when players completed very-high workloads during long between-match recovery times. Collectively, these findings are in agreement with others—absolute acute workloads are not as predictive of injury as acute:chronic workload ratios.[11] Furthermore, previous research has shown that when acute:chronic workload ratios below 1 are prescribed, higher workloads between matches are associated with a greater number of victories in team sport.[12]

Practical implications for team coaches and strength/conditioning personnel

Collectively, these findings may be attractive to coaches and practitioners hoping to implement higher training workloads between matches. However, attention to the myriad of factors other than workload, which are related to injury risk[27] and to the risk factors for overtraining and illness should also be considered when planning and prescribing between-match workloads.[28] For example, long-term excessive workload can cause non-functional over-reaching, characterised by decreases in performance and vigour and increased fatigue.[28,29]

Previous studies may support our findings that a high chronic workload can reduce the risk of match injury. Specifically, Gabbett *et al* demonstrated that rugby league players with greater aerobic capacity,[30] and prolonged high-intensity running ability[31] have a lower risk of injury. Furthermore, only 2 weeks of low-volume sprint interval training is required to elicit improvements in the high-intensity, intermittent running ability and aerobic capacity of team sport athletes.[32] Therefore, considering that rugby league training and match play involves sprinting efforts interspersed with low-intensity activity,[33,34] the athletes in the current study that achieved a higher chronic workload may have improved or maintained these physical qualities and in turn decreased their risk of sustaining a match injury when provided a short recovery between matches. However, for chronic workloads to be increased and provide resistance to injury, an acute:chronic workload ratio greater than 1 must be cautiously prescribed at strategic periods throughout the season. The findings of the present study suggest that the associated injury risk would be lower if workloads were increased during between-match recovery times of 7 or more days, with an acute:chronic workload ratio between 1 and 1.5.

Limitations and future directions

Valid analysis of injury risk in relation to collisions, high-speed running and accelerations is not possible with the GPS equipment used in this study.[15–19] Injury risk in team sport athletes can also be attributed to multiple factors that have not been included in this study.[23,27] However, to achieve the statistical power required to investigate other factors such as previous injury, age and physical fitness, in conjunction with the modifiable and non-modifiable injury risk factors in the present study, would require a considerably larger data set comprising many teams over a number of seasons.[23] Of course that brings with it the confound of different training regimens (an inherent limitation of 'ecological' research).

Summary and conclusion

Our data demonstrated that when short and long between-match recovery times are viewed in isolation, no difference in injury risk occurred. This study suggests that low chronic workloads, and the acute:chronic workload ratio are more predictive of injury than merely the recovery time provided between matches. Specifically, a higher chronic workload provides protection against a spike in acute workload, which was associated with the greatest risk of match injury in this study. Furthermore, provided that very-high acute:chronic workload ratios (~1.5) are avoided, higher between-match workloads can be achieved without increasing injury risk in elite rugby league players. This study offers practitioners fresh insight of how a controllable factor (workload) can be modified to decrease match-injury risk during elite rugby league competition.

Contributors BTH, TJG and JAS are responsible for the concept and design of this project. Injury and workload data were collected by DL and BTH, respectively. BTH was responsible for data analysis. PC revised this manuscript and provided statistical expertise.

What are the findings?

- Without taking other factors into account, the match-injury risk following 'short' between-match recovery times (5 or 6 days) was 7.7%; this was no different to the match-injury risk of 6.8% following 'long' between-match recovery times (≥7 days).
- *Higher* workloads prior to short between-match recovery times may *decrease* injury risk, while sudden upgrades in workload will likely increase match-injury risk, regardless of the recovery time provided between matches.
- This study adds to the body of literature suggesting that the acute:chronic workload ratio should be considered when evaluating workload-related injury risk in various sports.

How might it impact on clinical practice in the future?

- Using these findings to plan training across a season, taking into account between-match recovery times, may decrease injury risk.
- The positive and negative influences of workload on injury risk may be useful for strength and conditioning coaches and clinicians involved in planning training programmes in elite rugby league.

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Competing interests None declared.

Patient consent Obtained.

Ethics approval UOW and ISLHD Health and Medical Human Research Ethics Committee.

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