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# Association of Daily Workload, Wellness, Injury and Illness during Tours in International Cricketers

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**ABSTRACT**

**Purpose:** To examine the relationship between player internal workloads, daily wellness monitoring, injury and illness in a group of elite adolescent cricketers during overseas competitions. **Methods:** Thirty-nine male international adolescent cricketers (17.5 ±0.8 yr) took part in the study. Data was collected over five tours across a three-year period (2014-2016). Measures of wellness were recorded, and daily training loads calculated using session-rating of perceived exertion. The injury and illness status of each member of the squad was recorded daily. Acute and chronic workloads were calculated using three days and fourteen days moving averages**.** Acute workloads, chronic workloads, and acute chronic workload ratios (ACWR) were independently modelled as fixed effects predictor variables. **Results:** In the subsequent week, a high 3-day workload was significantly associated with an increased risk of injury (Relative Risk [RR] = 2.51; CI = 1.70 to 3.70). Similarly, a high 14-day workload was also associated with an increased risk of injury (RR = 1.48; CI = 1.01 to 2.70). Individual differences in the load injury relationship were also found. No clear relationship between the ACWR and injury risk was found, but high chronic workloads combined with a high or low ACWR showed an increase probability of injury compared to moderate chronic workloads. There were also trends for sleep quality and cold symptoms worsening the week before an injury occurred. **Conclusion**: Although there is significant individual variation, short term high workloads and changing in wellness status appear to be associated with injury risk.


**Key Words:** Cricket, Workloads, Injury, Wellness

## INTRODUCTION

It is well established that injury rates can influence the success of a team [1] and consequently managing loads appear to be an essential part of reducing injury risk. Training loads comprise of both internal and external loads. External load relates to the amount of work completed, whilst internal loads are a measure of the relative physiological strain. This relationship is crucial in determining the stress and adaptive response [2]. Furthermore, the rate of loading is a critical factor in influencing performance and injury factor [3]. If loads are applied in a moderate and progressive manner, they may be protective against injury [2]. No single marker can be used to accurately predict when an athlete enters a maladaptive state, so a combination of both internal and external load measures, specific to the nature of the sport, is recommended [3,4].



Despite the increased use of global positioning system (GPS) to record load in the literature [5], external load of cricket fast bowling is predominantly measured using the number of balls bowled [6,7]. However, recently balls bowled has been shown to inadequately capture the cost of fast bowling [8]. Consequently a hybrid of the session-rating of perceived exertion (sRPE) [9], TRIMP and balls bowled has been used to model injury risk in cricket. Hulin, Gabbett, Blanch, Chapman, Bailey, Orchard [10] was the first to investigate this specifically in cricket and combined both external (balls bowled) and internal load data (sRPE x duration) to model injury risk in fast bowlers. Despite a significant relationship between acute (1-week) external workloads and increased injury risk in the current week, no relationships were demonstrated between sRPE's and injury risk in the current or subsequent week. However, when both the external and internal acute workload exceeded chronic (4-week rolling average) workload, resulting in an acute chronic workload ratio (ACWR) of >2.0, the relative risk of fast bowling injury was 3.3 to 4.5 times greater. As balls bowled does not appear to accurately reflect external workload [8], internal workloads may be more strongly associated with injury as it encompasses all aspects of training and competition.

It is also highlighted that progressively higher workloads may serve as a protective mechanism against injury [10]. Unfortunately, progressive sequenced training to develop high chronic training loads is not always feasible, particularly in adolescent cricket where overseas tours occur out of season. The nature of touring results in intensive training periods followed by a congested fixture period. These, intensive training periods have led to an increase catabolic environment during the competition period [11]. Whilst an increased catabolic environment does not necessarily directly influence performance, it can indicate the ability of the athletes to tolerate training load [12]. Short duration tours have resulted in an increased injury risk in many other sports [13,14] although it is unclear if cricket has similar traits. Even though a significant amount of a cricketer's career is spent touring various countries, the effect this has on injury risk is unknown. As less recovery between days of bowling has been shown to increase the risk of injury in young (14.7 $\pm$ 1.4 years) fast bowlers [6], it is hypothesised that touring would also be associated with a high risk of injury. A recent systematic review has highlighted the large quantity of self-reported measures of wellness that are used in sport [15]. However, despite this review the relationship with injury and well-being is inconclusive. Therefore, the aim of this study was to examine the relationship between internal workloads, daily wellness scores, injury and illness in a group of elite adolescent cricketers during overseas competitions.



## METHODS

### Participants

The sample comprised 39 male adolescent cricketers (17.5 $\pm$ 0.8 y) who were selected to play international age group cricket. Data were collected over five tours across a three-year period (2014-2016). Tour duration varied from 18 to 30 days with a mean tour duration of 24$\pm$5 days. Of the five tours, 26% of the participants (n = 10) played one tour, 53% (n = 20) played two tours and 21% (n = 8) played three tours – equating to 1862 training days. Data were collected as a part of the routine practices throughout the tour season to which all players had consented [16]. The project was approved by St Mary's University Ethics Committee in the spirit of the Helsinki Declaration.

### Wellness Data

Subjective measures of wellness were recorded each morning at breakfast using a five-point scale for sleep quality and duration, muscle soreness, cold symptoms and mood with lower scores being indicative of reduced wellness [17].

### Internal Workload

Players were asked to provide a subjective rating of perceived exertion (RPE) using a 10-point rating scale [9]. The intensity of all sessions (games, cricket training and strength and conditioning) were recorded within 30 mins of completing the session. Daily training loads were then calculated by multiplying session RPE by session duration (min).

### Injury Data Collection

The programme's physiotherapist collected the data throughout the course of the study and the same practitioner was the programme physiotherapist for the duration of the study. A programme day was defined as any day where the squad was together, be it for a match, training, rest or travel day. For each programme day the squad physiotherapist recorded the injury status of each member of the squad on a specifically designed spreadsheet. A broader definition of injury and illness, as used in the current study, provides a more complete picture of the true burden of injury and illness than a time loss definition of injury and illness. The recent international injury consensus statement on injury surveillance[18] in cricket updated its definition of a cricket injury to include medical attention conditions and our paper is consistent with this consensus statement. Each player's injury status was recorded as being either:

1. Fully available for training and matches, with no injury or illness

2. Fully available for training and matches, but with an injury or illness

3. Available for selection in a major match, but with modified activity due to injury or illness

4. Unavailable for selection in a major match due to injury or illness

Non time-loss injuries were category 2 and 3 and time-loss injuries were category 4. All new injuries, as well as any pre-existing injuries players carried into the programme were reported. It was possible for a player to have multiple injuries or illness at any one time e.g.

they may have a medical condition while being treated for a musculoskeletal condition or they may have two or more musculoskeletal conditions requiring management at the same time.

A change in injury status occurred when a player's injury status changed from one to another e.g. a player sustained a hamstring strain and was unavailable for selection (category 4), but the previous day they were fully available with no injury or illness (category 1). Only injury status changes where the players' condition worsened i.e. they required increasing medical attention or activity/participation restriction; were included for analysis. This was a negative injury status change. This occurred when their injury status category number increased and was considered a negative status change.

For each injury or illness, the squad physiotherapist also recorded the players skill group, the side, region and location of injury, diagnosis based on the Orchard sports injury classification system 10 (OSICS10) [19] and the number of programme days spent in each injury status category. In addition, the mode of injury onset, activity at the time of onset and whether it occurred on a match or non-match day was recorded as well. Skill group was defined as per the international consensus statement guidelines [18], with players classed as either batsman, pace bowlers, slow bowlers or wicketkeepers. The mode of onset followed the consensus statement guidelines (Orchard, Ranson, Olivier et al, 2016), and was defined as either sudden onset, impact (blow or contact), gradual onset, insidious or illness. Sudden onset injuries comprised non-impact muscle strains and ligament sprains e.g. an ulnar collateral ligament sprain during a one-off throw. Impact injuries occurred because of contact with another player or object e.g. a contusion due to being hit by the ball. A gradual onset injury was where the condition developed over time e.g. a rotator cuff tendinopathy from repetitive throwing. An insidious onset was where there was no identifiable activity associated with a musculo-skeletal injury. Illness was any medical condition not associated with the other four mechanisms.

Data Analysis

'Programme' exposure was calculated by multiplying the number of players in each squad during each day of the programme by the number of programme days, using the following formula:

$$Programme\ player\ days\ = (daily\ squad\ size\ x\ number\ of\ days\ on\ programme)$$

Statistical Analysis

All estimations were made using the lme4 package with R (version 3.3.1, R Foundation for Statistical Computing, Vienna, Austria). Acute and chronic workloads were calculated using exponentially-weighted moving averages with time constants of three days and fourteen days, respectively [20]. These time frames were chosen to reflect the 'tour' format of the competitions analyzed (i.e., 18 to 30 day tours with limited chronic loading) and because exponentially-weighted moving averages have shown stronger relationships with injury risk than the usual one and four week rolling periods [21]. Uncoupled ACWR were calculated by reporting acute workloads (i.e., fatigue) as a proportion of chronic workloads (i.e., fitness) [10], such that acute load periods were not included in the calculation of chronic load [22]. Within-individual Z-scores were calculated for each player using the following formula:

(individual player's score – individual player's average)/individual player's standard deviation; a Z-score is the number of standard deviations the response is above or below the mean of the distribution.

A generalized linear mixed-effects model (GLMM) was used to model the association between workloads and injury risk in the subsequent week. This mixed effects model was selected for its ability to account for repeated measurements, and to explore individual responses between workloads and injury risk. Acute workloads, chronic workloads, and ACWR were independently modelled as fixed effects predictor variables. In addition, the interaction between ACWR and both acute and chronic workloads was assessed by including multiplicative terms in the model. Random effects were athlete identity (differences between athletes' mean injury risk), athlete × tour (variability within athletes between tours), and the residual. If assessment of a quadratic trend between the workload measure and injury risk was significant ($P \leq 0.05$), the measure was split into tertiles for analysis, with the lowest load range being the reference group. Otherwise, linear effects for continuous predictor variables were evaluated as the change in relative injury risk (RR) associated with a two standard deviation increase in the workload or wellness measure (representing the change associated with a 'typically low' versus a 'typically high' value of the predictor) [23]. The odds ratios obtained from the GLMM model were therefore converted to RR in order to interpret their magnitude [24]. The RR represents the change in injury risk associated with changes in the investigated load or wellness variables. A RR of 1.0 represents no change in risk of injury, whilst values of 0.5 and 2.0 would represent a halving or doubling of injury risk, respectively.

Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcomes [25]. The smallest important increase in injury risk was a RR of 1.11, and the smallest important decrease in risk was 0.90 [25]. 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. 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 likely [26]. The *r2glmm* package was used to determine whether model fit was significantly improved when using GLMM in comparison with a logistic regression model (which does not account for repeated measurements or individual variations in responses).

RESULTS

Thirty-nine players were involved in 1862 programme days during the study. There were 98 injuries in 38 players that resulted in 130 negative injury status changes on 125 different programme days. Only 17 (13.1%) of these changes resulted in the player being unavailable for match selection (category 4). On average players had a negative injury status change every 14.3 days. In most negative status changes (53.1%) players went from being fully available to receiving medical attention (change status from category 1 to 2), the next most common status changes were from fully available to modified activity (category 1 to 3) with 20% of all changes; and from medical attention to modified activity (category 2 to 3) with 13.8% of all changes. Sixteen pace bowlers accounted for 43.7% of all programme days and 46.9% of all negative status changes, nine spin bowlers accounted for 24.9% of programme days and 26.9% of all changes, nine batsmen accounted for 19.8% of programme days and 15.4% of all changes and five wicketkeepers accounted for 11.6% of programme days and 10.8% of all changes. Compared to pace bowlers (RR = 1.00 (ref)), wicket keepers and batsmen had a lower overall risk of injury (RR = 0.56; CI = 0.29 to 1.08), whilst the inference for spin bowlers was unclear (RR: 0.70, CI = 0.31 to 1.57).

****Insert Table 1 here****

Wellness and Injury Risk

No relationship was found between wellness scores and injury risk in the subsequent week, although there were trends for sleep quality and cold symptoms to worsen the week before an injury occurred (Table 1).

****Insert Table 2 here****

Acute and Chronic Workloads

In the subsequent week, a high (>0.35) 3-day workload z-score was significantly associated with an increased risk of injury (RR = 2.51; CI = 1.70 to 3.70; likelihood range >99.5%, most likely), compared with medium (-0.45 to 0.35) and low (<-0.45) workload z-scores (Table 2). The predicted probability of injury increased from 6% to 11% as 3-day workload increased from medium to high categories. This is in comparison to overall risk of pace bowlers (RR = 1.00 (ref)), wicket keepers and batsmen (RR = 0.56; CI = 0.29 to 1.08), spin bowlers (RR: 0.70, CI = 0.31 to 1.57).

****Insert Table 3 here****

A high (>0.67) 14-day workload z-score was also associated with an increased risk of injury (RR = 1.48; CI = 1.01 to 2.70; likelihood range 75-95%, likely), compared with medium (-0.45 to 0.35) and low (<-0.45) workload z-scores (Table 3). The predicted probability of injury increased from 8% to 13% as 14-day workload increased from medium to high categories.

****Insert Table 4 here****

The ACWR was not clearly associated with injury risk (Table 4). Both acute and chronic workloads were independently associated with injury risk in a linear fashion (Figure 1), with 2 standard deviation increases in both predictors (620 AU and 538 AU, respectively) associated with substantial increases in injury risk (Acute: RR: 1.82, CI = 1.34 – 2.47, most likely harmful; Chronic: RR: 2.22, CI: 1.56 – 3.15, most likely harmful).

****Insert Figure 1 here****

Additionally, there was a clear interaction effect between ACWR categories and chronic workloads (Figure 2), such that the effect of increasing chronic workloads on injury risk was substantially higher in the 'low' and 'high' ACWR categories, compared to the 'moderate' ACWR category. There was no interaction effect observed between ACWR and acute workloads (P = 0.30).

****Insert Figure 2 here****

There was a substantial improvement in model fit when random effects were included in the model (logistic regression model $R^2$ = 10%, GLMM model $R^2$ = 27%, P<0.001). Therefore, individual differences in workload-injury relationships were evident. Figure 3 displays the relationship between chronic workloads and injury risk in the subsequent week for each individual in the analysis, as estimated via the GLMM.

****Insert Figure 3 here****

## DISCUSSION

This is the first study to establish specific workload thresholds for adolescent cricketers and also non-fast bowlers. The study had numerous key findings. Firstly, high short-term (3 days) workloads (>2125 AU) or a high 14 day workload (>7212 AU) were also associated with an increased injury risk. Secondly, high chronic loads combined with a high or low ACWR increases the probability of injury compared to moderate chronic loads. Thirdly, individual differences in injury risk was also demonstrated between players. Finally, sleep quality and cold symptoms showed a trend with injury risk.

The findings from our study show that high short-term workloads in cricket (>2125 AU) increase the risk of injury. High workloads and increased injury risk may be a result of in-adequate recovery time between sessions. Particularly during the early days of touring, an optimal balance between intensity and volume of training and recovery needs to be implemented. These findings are in-line with previous sports such as rugby [27] and football [28]. In contrast to our findings, previous work in cricket [10] has found no link between acute internal workload measures and injury risk. One explanation for the difference could be the age and experience of the players involved in the study. Hulin, Gabbett, Blanch, Chapman, Bailey, Orchard [10] used older (26 $\pm$ 5 yr), more experienced cricketers who have had exposure to higher chronic workloads compared to the younger (17.5 $\pm$ 0.8 years) adolescent cricketers in our study. Individuals with a greater physical training history or greater physical attributes have also shown better tolerance to acute spikes in load better than younger individuals [29]. Therefore, the finding of greater injury risk with rapid acute changes in load in adolescent cricketers may be expected. Conversely, older athletes appear to be at greater risk of injuries at a given absolute training load than younger athletes [30]. Whilst this appears to be a contradictory finding, there may be a ‘sweet spot’ for age, physical qualities and training history where athletes can cope with acute spikes in training loads. Other differences between the findings in this study may due to the classification or change in injury states we used compared to time loss data [10]. Our study also used a change in injury status that is more reflective of current sporting practices.



The non-significant relationship between the ACWR and risk of injury or illness is in contrast to previous work in senior cricket fast bowlers [10] and elite adolescent cricketers [31]. Our findings uniquely show that high chronic loads combined with a high or low ACWR increases the probability of injury compared to moderate chronic loads. Previously, higher chronic workloads have shown to serve as an injury protective mechanism for acute spikes in workload [32]. Conversely, high chronic loads can be achieved safely so long as the ACWR is not excessive. Despite being beyond the scope of this study, it seems essential that the workload prior to touring is recorded. If players have accumulated large workloads before touring then ensuring ACWR is not minimised or excessive would appear to reduce the risk of injury.

Individual differences in injury risk were also demonstrated between playing positions for the first time showing that athletes should understand individual responses to chronic workloads. Prescribing individual load is often very difficult in a team setting, but our data suggests that ensuring all players are below (>2125 AU) will reduce the risk of injury. The length of the acute window has also been shown to be strongly associated with injury [33]. Given that players do not have the opportunity to build chronic workloads prior to touring, our study used time frames of 3 and 14 days for acute and chronic loading periods. Work has predominantly used time frames of 7 and 28 days though there is evidence to suggest that 6 and 21 days acute to chronic workload ratios is optimal for predicting injuries [33]. Consequently, it could be suggested that the 3 days used for the acute period in our study was not long enough to see differences in ACWR.



A positive link between alterations in training load and subjective measures of well-being has previously been established [34,35]. A recent systematic review [15] has highlighted that subjective well-being measures respond consistently to stress imposed by training. Of 56 research articles, 85% favoured subjective measures when monitoring athlete load. Negative changes in wellness measures have also been linked to increased risk of illness [36], although changes in wellness measures and risk of injury has received less attention [37]. The result from our study showed no significant relationship between subjective measures and injury and illness. A possible explanation for these findings may be the due to the scale used. Our study used a 5-point scale where previous work has shown that a greater number of points on a scale increases the sensitivity [38]. However, we did observe trends of reduced sleep and self-reported cold symptoms in the week before an injury occurred. Recent work by von Rosen, Frohm, Kottorp, Friden, Heijne [37] supports this notion and demonstrated that in youth athletes, an increase in training load and intensity in addition to a decrease in sleep volume significantly increased the risk of injury. With even modest sleep loss associated with impairment of psychomotor performance [39] it appears logical that assessing sleep volume and quality is a key subjective measure for reducing injury and illness risk.

## LIMITATIONS

Although higher chronic workloads have been shown to be associated with a lower risk of injury, it was not possible to quantify chronic training workloads in the period prior to tours. Therefore, future work should focus on the workloads preceding a tour and the effects this has on injury prevalence. Subjective measures of wellness were asked during breakfast. Whilst the experimenters made every attempt to ensure this was performed away from other coaches and players, the nature of the touring environment sometimes meant wellness measures were not performed in isolation. Finally, the nature of cricket often involves large periods of very low inactivity such as fielding in a match. This low RPE but long duration can often cause excessively large TRMP values.

## CONCLUSION

Collectively, these results demonstrate that in elite adolescent cricketers, high acute and/or chronic internal workloads are significantly associated with an increased risk of injury. Rapid increases in acute workloads >2125 AU are more closely associated with injury and illness than ACWR assessed over 3 and 14 days respectively. High chronic loads combined with a high or low ACWR increases the probability of injury compared to moderate chronic loads. Therefore, practitioners should ensure individuals that accumulate large amounts of workload have a moderate ACWR whilst touring. However, the injury risk appears to be an individualised response. We have demonstrated for the first time that other cricket skill sets (in addition to fast bowling) have injury risks associated with workloads. Although not significant, measures of wellness, specifically sleep duration and self-reported cold symptoms can be expected to worsen the week before an injury occurs.

## PRACTICAL IMPLICATIONS:

- The non-invasive and simple session-RPE method is useful for tracking training and game loads and injury risk during elite adolescent cricket tours.
- Coaches should avoid spike in workloads when chronic workloads are high or low.
- Players appear to be at an increased risk of injury when they experience a high 3 day cumulative load (≥2125 AU), though there are individual differences.
- Although not significant, worsening sleep quality and self-reported cold symptoms are possible subjective indicators of heightened injury risk in this population. These measures warrant further investigation in larger studies in the future.

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**Table 1.** Change in injury risk associated with a 2SD improvement in self-reported wellness indicator.

| Wellness | Relative risk | Lower CL | Upper CL | Inference | P-value |
|---|---|---|---|---|---|
| Total wellness | 0.96 | 0.82 | 1.13 | Unclear | 0.70 |
| Sleep duration | 0.98 | 0.83 | 1.16 | Unclear | 0.87 |
| Sleep quality | 0.89 | 0.76 | 1.05 | Possibly ↓ | 0.25 |
| Body feeling | 0.91 | 0.77 | 1.08 | Possibly trivial | 0.35 |
| Cold symptoms | 0.86 | 0.72 | 1.02 | Possibly ↓ | 0.15 |
| Mood | 1.00 | 0.84 | 1.18 | Unclear | 0.98 |

**Table 2.** Acute and chronic workloads express as AU and z-scores

| | Z-Score | sRPE AU's |
|---|---|---|
| **Acute Workload (3 Days)** | | |
| Low | <-0.45 | 523 - 1322 |
| Medium | -0.45 to 0.35 | 1323 - 2124 |
| High | >0.35 | >2125 |
| **Chronic Workload (14 Days)** | | |
| Low | <-0.40 | 2051 - 5128 |
| Medium | -0.4 to 0.67 | 5129 - 7211 |
| High | >0.67 | >7212 |

**Table 3.** Predicated probability of injury expressed relative to z-scores.

| | Relative risk | Lower CL | Upper CL | Inference | P-value |
|---|---|---|---|---|---|
| **3-day load z-score** | | | | | |
| Low (<-0.45) | 1.00 (ref) | | | | |
| Medium (-0.45 to 0.35) | 1.18 | 0.73 | 1.93 | Unclear | 0.56 |
| High (>0.35) | 2.40 | 1.57 | 3.66 | Most likely ↑ | 0.0007 |
| **14-day load z-score** | | | | | |
| Low (<-0.40) | 1.00 (ref) | | | | |
| Medium (-0.40 to 0.67) | 1.18 | 0.82 | 1.71 | Unclear | 0.46 |
| High (>0.67) | 1.89 | 1.26 | 2.85 | Most likely ↑ | 0.01 |

**Table 4.** Predicted probability of injury risk.

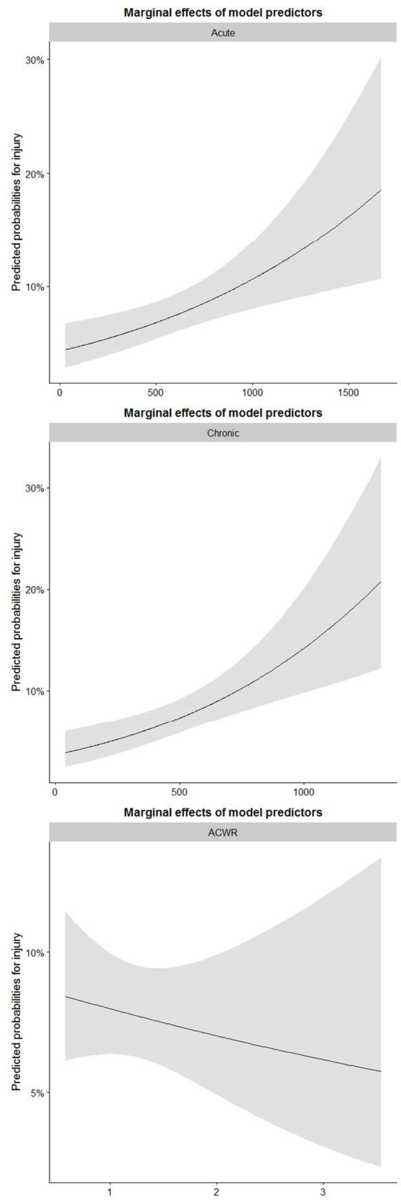
| Acute:chronic workload | Relative risk | Lower CL | Upper CL | Inference | P-value |
|---|---|---|---|---|---|
| Low (<0.80) | 1.00 (ref) | - | - | - | - |
| Medium (0.80 to 1.30) | 0.99 | 0.64 | 1.56 | Unclear | 0.99 |
| High (>1.30) | 1.01 | 0.65 | 1.58 | Unclear | 0.96 |

**Figure Legends**

**Figure 1.** Acute, chronic and acute chronic workload ratio probability of injury.

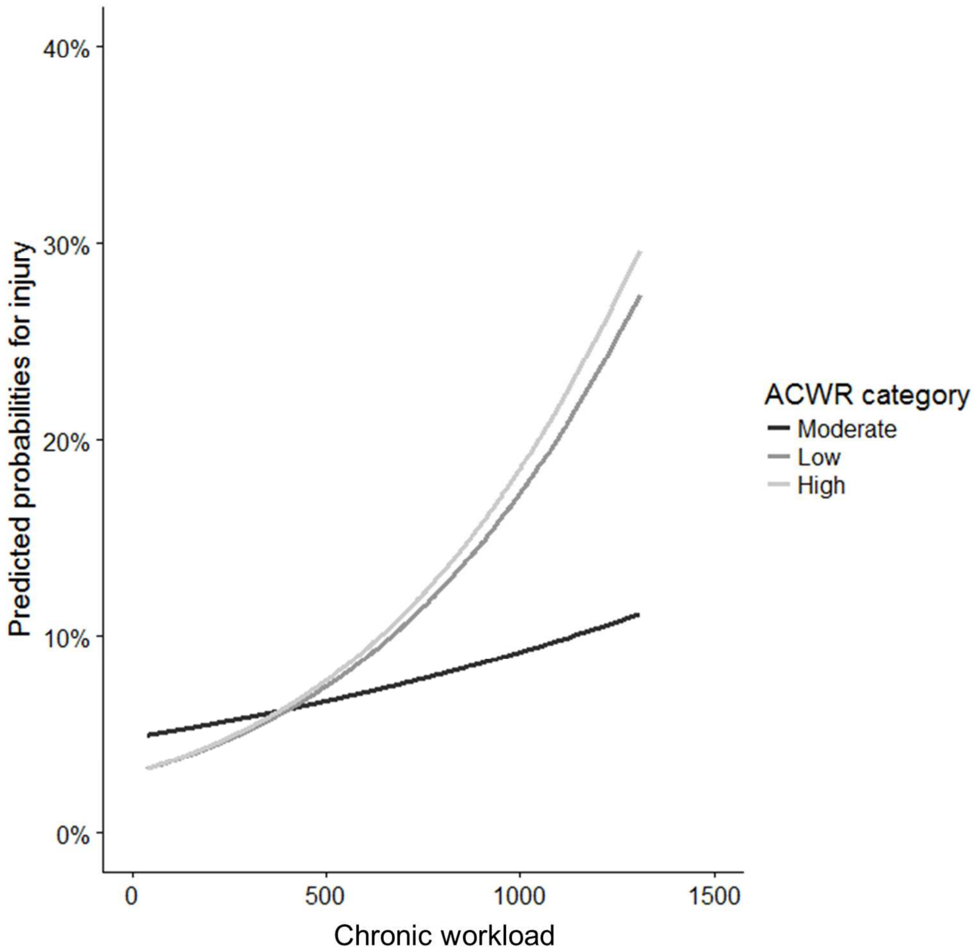
**Figure 2.** Acute, chronic and acute to chronic workload ratios association with injury risk.

**Figure 3.** Relationship between chronic workloads and injury risk in the subsequent week for each individual. Primary role is defined. BAT = Batsmant; PB = Pace Bowler; SP = Seam Bowler; WK = Wicket Keeper.




Acute, chronic and acute chronic workload ratio probability of injury.

99x299mm (300 x 300 DPI)




Acute, chronic and acute to chronic workload ratios association with injury risk.

129x129mm (300 x 300 DPI)


Figure 3. Relationship between chronic workloads and injury risk in the subsequent week for each individual. Primary role is defined. BAT = Batsmant; PB = Pace Bowler; SP = Seam Bowler; WK = Wicket Keeper.

275x190mm (300 x 300 DPI)