

Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries

John W Orchard,^{1,2} Peter Blanch,² Justin Paoloni,^{2,3} Alex Kountouris,² Kevin Sims,² Jessica J Orchard,¹ Peter Brukner²

¹School of Public Health, University of Sydney, Sydney, New South Wales, Australia
²Cricket Australia, Melbourne, Australia
³Orthopaedic Research Institute, University of New South Wales, Sydney, Australia

Correspondence to

Dr John W Orchard,
Cnr Western Ave & Physics Rd,
University of Sydney 2006
Australia;
johnworward@gmail.com

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ABSTRACT

Objective To assess workload-related risk factors for injuries to particular tissue types in cricket fast bowlers. **Design** 235 fast bowlers who bowled in 14600 player innings over a period of 15 years were followed in a prospective cohort risk factor study to compare overs bowled in each match (including preceding workload patterns) and injury risk in the 3–4 weeks subsequent to the match. Injuries were categorised according to the affected tissue type as either: bone stress, tendon injuries, muscle strain or joint injuries. Workload risk factors were examined using binomial logistic regression multivariate analysis, with a forward stepwise procedure requiring a significance of <0.05.

Results High acute match workload and high previous season workload were risk factors for tendon injuries, but high medium term (3-month workload) was protective. For bone stress injuries, high medium term workload and low career workload were risk factors. For joint injuries, high previous season and career workload were risk factors. There was little relationship between muscle injury and workload although high previous season workload was slightly protective.

Conclusions The level of injury risk for some tissue types varies in response to preceding fast bowling workload, with tendon injuries most affected by workload patterns. Workload planning may need to be individualised, depending on individual susceptibility to various injury types. This study supports the theory that tendons are at lowest risk with consistent workloads and susceptible to injury with sudden upgrades in workload. Gradual upgrades are recommended, particularly at the start of a bowler's career to reduce the risk of bone stress injury.

INTRODUCTION

Exercise is now recognised as a major preventive risk factor for the majority of diseases and requires aggressive promotion by health authorities.¹ However, exercise prescription is not as straightforward as it might appear, as sudden increases in physical activity and sport are associated with injuries, particularly tendon injuries.^{2–5} The current surveillance and understanding of the causes of gradual onset (sometimes termed 'overuse') injuries associated with sport and exercise are poor,^{6, 7} making it difficult to recommend ideal amounts of exercise. It is particularly difficult to prospectively assess loading risk factors for tendon injuries, as keeping detailed long-term records of tendon loading is particularly arduous and expensive. Understanding risk factors for gradual onset tendon injuries may be more easily improved by following elite athletes⁸ for whom detailed loading records

are often kept. However, the difficulty with assessing elite athletes is that the majority are subjected to a high, but fairly constant workload, increasing the challenge of assessing the effects of workload changes on injury risk.

Of the major global team sports, cricket has both a high rate of gradual onset injuries and great variations in player workload.⁹ Whereas most team sports are played over a short and fixed duration, cricket is played in a variety of forms. Balls in cricket are delivered in groups of six, called 'overs'. Therefore, 20 overs in cricket consist of 120 balls. One-innings matches are played with a maximum number of set overs (usually 20 or 50 overs at international level) to be bowled in each team's (single) innings, with each bowler being allowed to bowl a maximum number of overs (usually 20% of a team's total overs). Limited overs matches with 20 overs per team are often referred to as 'T20' matches. First class cricket matches (including international Test matches) are played with unlimited overs lasting 4 or 5 days (with two innings per team). The length of an innings in first class cricket is not fixed, which leads to great variation in workloads. In these matches, bowlers can sometimes be required to bowl in excess of 50 overs (300 balls) over the 4–5 days. In addition, the international cricket calendar is fairly unstructured, with no fixed number of matches of the various varieties for the major national teams. Cricket is also the only major team sport where substitute players are not permitted for most facets of the game (fielding substitutes are permitted, but bowling substitutes are not). When a team loses a bowler to injury, other bowlers tend to increase their workloads to make up for the missing player.¹⁰ These factors make cricket an ideal sport to study for the development of gradual onset injuries.

Broadly speaking, there are two major bowling types in cricket: fast bowling (also known as pace bowling) and spin bowling. For the purpose of this paper, the term 'fast bowlers' refers to bowlers who bowl fast, medium-fast or medium (ie, bowling with a fast run-up, with ball speed generally above 100 kph and where the wicketkeeper will generally stand back from the stumps), as opposed to spin bowlers to whom the wicketkeeper would normally stand up to the stumps. Fluctuations of game type, innings length and the variable schedule impacts fast bowlers more than others. Fast bowlers are the most prone to injury,^{11, 12} which is generally of a gradual onset nature. The fast bowling motion involves a run-up and straight-arm hurling (not throwing) movement with the predominant associated injuries occurring to the lumbar spine¹³ and

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lower limb.^{12–14} For clarity, it is noted that the term ‘workload’ in this paper refers to match bowling load. When comparing cricket to baseball workloads,¹⁵ there appears to be a slightly greater tolerance to bowling loads in cricket than pitching loads in baseball. Although 20 overs (120 balls) in a day is still a very high workload in cricket, a fast bowler would still be able (and be expected) to bowl again the following day if necessary, whereas a baseball pitcher who had pitched 120 times would usually have a minimum of 3 days rest before being able to competitively pitch again.

Bowling workload as a risk factor for gradual onset injury in cricket has been previously reported.^{16–18} High and low overall bowling loads (expressed in terms of balls bowled per week or sessions bowled per week) have been found to increase injury risk in fast bowlers. There is a relationship between the overall bowler workload (matches and training) and risk of bowling injury in both adult¹⁷ and junior¹⁶ cricket. A previous study from the Cricket Australia cohort of fast bowlers found that high acute workloads (>50 overs in a first class game or >30 overs in the second innings of a first class game) led to increased injury risk in the subsequent month.¹⁹ Sudden sharp increases in workload are also associated with increased injury risk.¹⁸ This may partially explain why injury rates have increased somewhat since the widespread uptake of T20 cricket, as a bowler playing T20 over several weeks will only be exposed to low match workloads and therefore, might then be underprepared for a return to the higher workloads in subsequent first class cricket.⁹

The objective of this study was to examine workloads in fast bowlers during and prior to cricket matches and to investigate relationships between workload and injury risk for different tissue subtypes (bone, muscle, tendon and joint).

MATERIALS AND METHODS

Cricket Australia conducts an annual injury survey of contracted first class players. Methods for this survey have been described previously.¹¹ The methods used for Cricket Australia injury surveillance are non-interventional, conform to the Code of Ethics of the World Medical Association (Declaration of Helsinki), and have been approved by the Cricket Australia Sports Science Sports Medicine Advisory Group.

This was a prospective cohort study investigating relationships between injury risk and workload status in fast bowlers. The analysis was performed for fast bowlers over 15 seasons, 1998–1999 to 2012–2013 inclusive. De-identified bowling injury data (injuries sustained while bowling) were extracted from the pre-existing database. Workload data were extracted from the official scorecards in first class and List A matches (1-day and T20 matches), and relate to match workloads from this level of games only. Training workload and match workload from lower level matches (eg, club games) or overseas games not involving Australian teams were not available.

Injury definition

In 2005, cricket researchers published consensus international injury definitions for the sport and the methods of this survey adhere to the international definitions.^{20–21} The definition of a cricket injury (to a bowler) is one that either: (1) prevents a player from being fully available for selection in a major match (which is a List A or first class match), or (2) during a major match, causes a player to be unable to bat or bowl when required by either the rules or the team’s captain.

This study concerns fast bowling injuries only and therefore, includes a data set of injuries in fast bowlers sustained either

with an acute non-contact bowling mechanism or a gradual onset bowling mechanism. Injuries in bowlers which were sustained either when batting or fielding (including being struck by a batted ball when bowling) were not included as part of this study. Although workload data were not available for training sessions and lower level matches, injuries that occurred in these settings which prevented participation in matches were included.

Injury diagnosis

Injuries were coded using the OSICS V.9 system.²² The second character of the injury diagnosis was used to subcategorise bowling injuries into muscle, bone stress, tendon or joint injuries.

Statistical analysis

Importantly, the injury data set under consideration for each match workload only included those injuries occurring *after* the match in question for a fixed time period. That is, when considering the number of overs bowled in the reference match, injuries which occurred during the match in question were excluded from the analysis, as the injury would have the effect of confounding the number of overs bowled during that match (because the player will usually, but not always, stop bowling after the injury). Periods of 21 and 28 days after the match were analysed as these time periods were previously found to be most significantly related to match workloads.¹⁹

Risk factors considered were: bowling load in the reference match and match workloads (for all major cricket competitions involving Australian teams) in the previous 3 months, previous season (season prior to current one) and career. The workloads were converted to binary status at various round number cut-off points to attempt entry into a logistic regression equation. The cut-offs used were: single match workloads (<30 or ≥30, <40 or ≥40 and <50 or ≥50 overs); previous 3 months workload (<150 or ≥150, <200 or ≥200 overs); previous season workloads (<300 or ≥300, <350 or ≥350, <400 or ≥400 and <450 or ≥450 overs) and career-to-date workloads (<1000 or ≥1000, <1200 or ≥1200, <1400 or ≥1400, <2000 or ≥2000 and <3000 or ≥3000 overs). Type of match (whether limited overs or first class) was included in analyses as a potential risk factor, as was injury status from an earlier match in the current season (whether the player had previously been injured that season or not). Age was not included as a potential risk factor because it was likely to correlate highly with career workload.

A multivariate analysis was conducted using binary logistic regression in SPSS V.15.0.²³ A forward stepwise method was used, with a p value of <0.05 required for a risk factor to be included at each step. The logistic regression output presented for each type of injury in the results was the best predictive model. For example, if both injuries in the next 21 and 28 days could be significantly predicted by a logistic regression model, the period which gave the best predictive model was utilised. Similarly, if both previous season workload of ≥350 and ≥400 overs were significant risk factors for injury, the cut-off which gave the strongest prediction was utilised.

RESULTS

The data set included 235 fast bowlers over a 15-year time period who bowled in 14 600 player innings. They suffered 366 muscle injuries (most commonly hamstring, quadriceps, calf, adductor and side strains), 131 tendon injuries (most commonly rotator cuff, patellar, Achilles and groin tendon injuries), 120 bone stress injuries (most commonly lumbar, shin and foot

Table 1 Risk factors for fast bowlers developing a tendon injury in next 21 days

Variable	B value	SE	Significance p value	OR	95% CIs (low-high)	
Acute match overs ≥ 50	1.30	0.39	0.001	3.69	1.82	8.24
Career overs ≥ 1200	0.87	0.19	0.000	2.38	1.65	3.42
Overs in previous season ≥ 400	0.70	0.19	0.000	2.01	1.38	2.94
Previous injury same season	0.61	0.16	0.000	1.85	1.33	2.55
Limited overs match	0.51	0.19	0.007	1.67	1.15	2.42
Overs in previous 3 months ≥ 150 (protective)	-1.25	0.28	0.000	0.29	0.17	0.50
Career overs ≥ 3000 (protective)	-1.44	0.40	0.000	0.24	0.11	0.52

stress fractures) and 78 joint injuries (most commonly knee, ankle and lumbar joint pathologies).

Tables 1–4 detail multivariate workload risk factors for developing injuries in the various subsets. Tendon injuries had the highest number of significant workload-related risk factors. Very high acute match workload (≥ 50 overs) and high previous season workload (≥ 400 overs) were risk factors for developing tendon injuries, but high medium term workload (3-month workload ≥ 150 overs) was protective. Low (< 1200 overs) and also very high (≥ 3000 overs) career workloads were protective for tendon injuries compared with medium or medium–high career workloads (1200–3000 overs). Playing in a limited overs match (ie, low acute match workload, ≤ 10 overs) and having had a previous injury (of any type) in the same season (which would have resulted in a period of zero match workload during the injury period) were also risk factors for tendon injury.

Table 2 shows that while low career workload (< 1200 overs) was protective against tendon injuries, it had the opposite effect for bone stress injuries (where it was a strong risk factor). High match workload in the previous 3 months (≥ 150 overs), and having had a previous injury in the same season were also risk factors for bone stress injury. Workload in the previous 3 months again had the opposite effect on risk for bone injuries than for tendon injuries (high workload in previous 3 months

was a risk for stress fractures but protective against tendon injuries).

Despite having the highest number of injuries of all of the tissue types, there were few significant risk factors predicting muscle injury in this model. Playing in a limited overs match was a risk factor, whereas having a high workload in the previous season was protective.

The risk factors for joint injury were high career workloads (≥ 3000 match overs) and high workload in the previous season (≥ 450 overs).

DISCUSSION

This study expands on a previous study from the same cohort¹⁹ showing that tissue susceptibility to injury varies according to preceding workload patterns. These variations are detailed in table 5 and figure 1. Since high workloads can increase or decrease injury susceptibility, the term ‘overuse’ injury is a misnomer, as both overuse and underuse are potentially relevant, particularly for tendon injuries. This has been previously described by other authors.² Underuse may increase susceptibility to injury, perhaps due to subsequent upgrades in workload.¹⁸ For both tendon and bone stress injuries, a pattern of relatively high long-term workload appears advantageous, unless upper limits are exceeded.

Tendon injuries appear to be particularly related to variations in workloads. For tendon injuries, previous injury in the same season (which would disrupt a workload pattern and create ‘underuse’) and > 50 overs in a game are risk factors for injury. High previous season workload (> 400 overs) is also a risk factor. However > 150 overs in the previous 3 months is protective, which suggests tendon injuries are ‘overuse/underuse’ injuries and that workload relative to conditioning (recent previous workload) is most relevant for tendon injury. This fits the theory that ‘you need to load to withstand load’,²⁴ with the caveat that there are upper limits that pose risk for all players.

For bone stress injuries, career match workload of ≥ 1200 overs is highly protective, whereas bowling > 150 overs in the previous 3 months increases risk. This highlights the dilemma

Table 2 Risk factors for fast bowlers developing a bone stress injury in next 28 days

Variable	B value	SE	Significance p value	OR	95% CIs (low–high)	
Overs in previous 3 months ≥ 150	0.74	0.18	0.000	2.10	1.48	2.99
Previous injury same season	0.54	0.16	0.001	1.71	1.25	2.34
Career list A overs ≥ 1200 (protective)	-1.18	0.20	0.000	0.31	0.21	0.45

Table 3 Risk factors for fast bowlers developing a muscle injury in next 21 days

Variable	B value	SE	Significance p value	OR	95% CIs (low–high)	
Limited overs match	0.29	0.11	0.009	1.34	1.08	1.67
Overs in previous season ≥ 400 (protective)	-0.34	0.15	0.020	0.71	0.53	0.95

Table 4 Risk factors for fast bowlers developing a joint injury in next 28 days

Variable	B value	SE	Significance p value	OR	95% CIs (low–high)	
Overs in previous season ≥ 450	0.67	0.28	0.015	1.96	1.14	3.37
Career list A overs ≥ 3000	0.61	0.30	0.042	1.84	1.02	3.31

Table 5 Comparison of workload interactions with different type of injuries

Type of injury	Acute workload (per match)	Medium term workload (3 months)	Previous season workload	Career workload
Tendon	High increases risk ++ (low also having + increased risk)	High is protective +	High increases risk +	High or low are protective ++ (compared with moderate)
Bone	No effect	High increases risk +	No effect	High is protective ++
Muscle	Low increases risk +	No effect	High is protective +	No effect
Joint	No effect	No effect	High increases risk +	High increases risk +

Effects ++ (medium) or + (small).²⁵

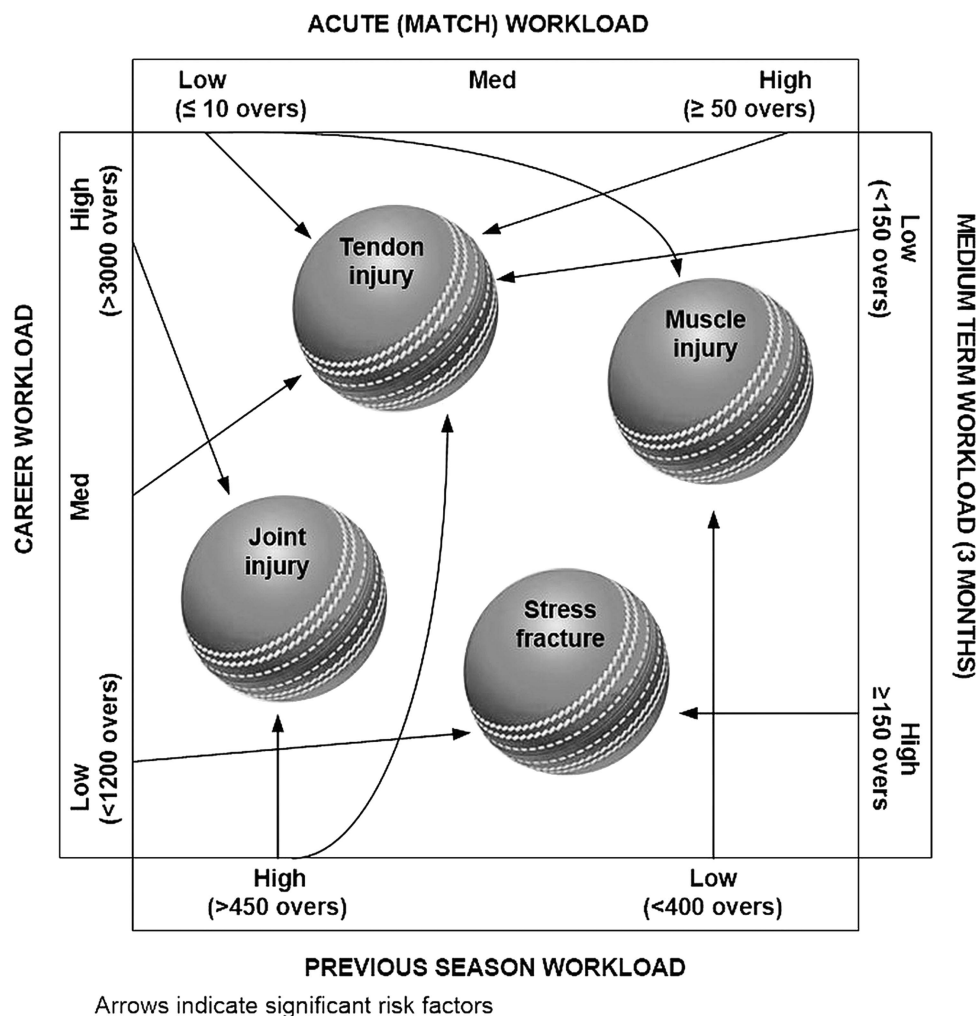
for young players that they must bowl overs to condition their bones to be able to withstand the high workloads expected of a professional fast bowler, but doing this too quickly might place them at high risk of suffering a bone stress injury.

Bowling workload in isolation appears to have relatively little impact on the risk of muscle injuries, although limited overs matches (which are likely to have greater high speed running exposure than first class cricket) are a risk for muscle strain injuries. For other sports, such as the football codes, it may be true that high workloads increase risk of injury although speed of the game appears to be a greater risk factor for hamstring injury than fatigue in Australian football.²⁶

Joint injuries are more prevalent in players with high career workload (≥ 3000 overs) and previous season workload

(≥ 450 overs). This indicates that high load over a longer period of time (season or career), rather than short bursts of high load (in a single match, week or month), predisposes joint injury. It should also be noted that perhaps older age is likely to be a concomitant factor as it is highly correlated to high career workload.

It is clear that for a mature player (particularly with respect to tendon injuries), conditioning with moderate workloads protects against subsequent injury. However, setting ideal workloads for an inexperienced fast bowler trying to break into regular first class cricket is difficult in that loading is important to protect against injury, but the loading process itself is a risk factor for developing injuries, such as stress fractures (which then require long recovery times). It is clear from the findings of

**Figure 1** Risk factors for various types of injury.

this study that workload has a complicated relationship with injury. It is neither true that “fast bowlers should bowl as much as possible to prevent injury” nor “fast bowlers bowl too much across the board and should all cut back on workload”. The general advice that is most accurate is that constant moderate workloads for fast bowlers probably protect best against injury, with a ‘moderate’ workload being 20–30 match overs per week, 150–200 match overs per 3 months and 400–450 match overs per season/year. The nature of scheduling matches means that it is obviously not always possible to keep match workloads within ‘ideal ranges’; however, these figures provide useful benchmarks that cricket coaches and support staff can use when planning player preparation and squad selection.

One limitation of this study is that the diagnostic categories chosen (bone, tendon, muscle and joint injury) are not always clear-cut. For example, chronic groin pain is common in cricket and may be diagnosed as including elements of both a tendon (adductor tendinopathy) injury and a bone (osteitis pubis) injury. Similarly, some common tendon impingement conditions occur within joints and could, therefore, be considered to be from both joint and tendon injuries. To avoid a perception of data manipulation, the second character of the OSICS9 injury code was utilised to denote tissue type. However, it is recognised that not all experts would agree with all consequent categorisations made using this method. Another limitation is that it is quite possible (and even likely) that the different subgroups of injury within each category will have different risk factors (eg, hamstring strain compared with calf strain). As greater sample sizes become available in the future, it is likely that risk factors for common specific diagnoses will be identifiable.

A further limitation is that the study was only able to analyse bowling workloads in major competitions involving Australian teams. Training workloads, overs bowled in competitions not involving Australian teams (eg, Indian Premier League or English County Cricket matches), and other risk factors, such as strength and joint range of movements, were not available. Player age was available, but was excluded due to it being strongly correlated with career workload, which was already included as a risk factor.

What are the new findings?

- ▶ High acute workload, low recent workload, high previous season workload and moderate career workload are risk factors for tendon injuries in cricket fast bowlers.
- ▶ Low career workload and high recent workload are risk factors for stress fractures in cricket fast bowlers.

How might this impact on clinical practice in the near future?

- ▶ Team support staff will, where possible, advise moderate rather than high or low workloads for cricket fast bowlers and perhaps, athletes in other sports.
- ▶ When a person is at high risk (eg, an inexperienced fast bowler with low recent workload because of previous injury), particular care is required to increase match workload gradually to avoid injury.

Despite these limitations, the findings of this study (particularly with respect to tendon injuries) are in keeping with the beliefs of experts in rehabilitation and injury prevention (eg, that for tendon injuries, constant moderate loads are protective, with acute overload and prior relative ‘underload’ being risk factors). With respect to career workloads and risk of each injury type, the findings are analogous to the injury patterns seen in a clinical sports medicine practice; younger patients more often present with bone stress injuries, middle-aged patients more often present with tendon injuries and older patients present with joint-related pathology.²⁷ In clinical medicine, bone stress injuries (including fatigue fractures of neck of femur and thoracic vertebrae) are also seen in the elderly population as well as the young (teenagers).

This is believed to be the first study to provide cricket fast bowling workload thresholds likely to be related to tissue-specific injury risk. The dilemma of undertaking enough workload to offer relative protection against some types of injury (eg, tendon injury) without increasing risk of developing another (ie, bone stress fracture) is a precarious balancing act, especially for inexperienced fast bowlers.

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Competing interests All authors declare potential competing interests due to receiving direct or indirect payments from Cricket Australia (for either or both of injury surveillance or medical service provision).

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