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The association between bowling volume and injury risk in elite South African Cricket fast bowlers

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Keywords:	Bowling volume, Injury, Pace bowlers, Workload, Cricket
Abstract:	BACKGROUND There has been no study investigating the association between bowling volume and injury risk among elite, South African fast bowlers. The purpose of this study was therefore to prospectively monitor fast bowler bowling volume and explore the association thereof to in-season injury risk. METHODS This study was an observational, cohort study that monitored bowling volume and injuries among fast bowlers playing for the South African national team (the Proteas) between April 2017 and April 2019. A sample of convenience was selected and included fourteen pace bowlers. Training and competition bowling volumes, as well as injuries, were recorded. Bowling volume was quantified as the number of balls bowled during training and competition. Acute-, chronic- and acute: chronic bowling volume ratios were independently modeled as predictor variables. RESULTS There were 39 injuries with the most being to the lumbar spine (25.64%) followed by the hip and groin (17.95%). There was a reduced risk of injury between a moderate-to-low and a moderate-to-high acute: chronic bowling load ratio. Chronic bowling load was a significant

predictor of injury occurrence (z = 2.82, p = 0.01). A low acute workload, low chronic workload, moderate-high chronic workload, and moderate-low acute: chronic ratio demonstrated a significant risk of injury.

CONCLUSION
These findings confirm that there appears to be a dose-response effect between training bowling volume and the likelihood of an injury occurring with a moderate-to-low and a moderate-to-high bowling volume ratio being optimal. Considering the small sample size, the findings should however be interpreted with caution.

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Running title: Bowling volume and injury risk in elite South African cricket fast bowlers

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ABSTRACT

BACKGROUND

There has been no study investigating the association between bowling volume and injury risk among elite, South African fast bowlers. The purpose of this study was therefore to prospectively monitor fast bowler bowling volume and explore the association thereof to in-season injury risk.

METHODS

This study was an observational, cohort study that monitored bowling volume and injuries among fast bowlers playing for the South African national team (the Proteas) between April 2017 and April 2019. A sample of convenience was selected and included fourteen pace bowlers. Training and competition bowling volumes, as well as injuries, were recorded. Bowling volume was quantified as the number of balls bowled during training and competition. Acute-, chronic- and acute: chronic bowling volume ratios were independently modeled as predictor variables.

RESULTS

There were 39 injuries with the most being to the lumbar spine (25.64%) followed by the hip and groin (17.95%). There was a reduced risk of injury between a moderate-to-low and a moderate-to-high acute: chronic bowling load ratio. Chronic bowling load was a significant predictor of injury occurrence ($z = 2.82$, $p = 0.01$). A low acute workload, low chronic workload, moderate-high chronic workload, and moderate-low acute: chronic ratio demonstrated a significant risk of injury.

CONCLUSION

These findings confirm that there appears to be a dose-response effect between training bowling volume and the likelihood of an injury occurring with a moderate-to-low and a moderate-to-high bowling volume ratio being optimal. Considering the small sample size, the findings should however be interpreted with caution.

Keywords: Bowling volume, Injury, Pace bowlers, Workload

Introduction

Compared to other players (batsmen, spin bowlers, wicketkeeper) on a cricket team, fast bowlers endure greater physical demands external workload requirements.[1,2] Irrespective of match format, fast bowlers cover 20–80% greater distances, exert two to seven times higher-intensity in terms of running speeds (ie., >4.01m/s) and have 35% less recovery time between high-intensity efforts.[1,2] Additionally, fast bowlers are at greater risks of sustaining injuries, missing approximately 16% of all potential playing time, whereas the prevalence rate for all other positions is less than 5%.[3] In addition to higher workloads, the fast bowling action further expose players to injury. This action requires an akward combination of lateral lumbar spine flexion, extension and rotation, whilst absorbing forces as high as eight times their body mass during the delivery stride.[4–6]

A holistic depiction of players' workload requires the measurement of both internal (biological stressors) and external (objective measure of work performed by an athlete) loads.[7,8] External load measures include the number of balls bowled and global position system (GPS) measures such as distances covered.[7,8] Higher absolute workload among fast bowlers is associated with greater injury rates.[9–12] These injuries are usually of gradual onset, overuse type injuries.[9–13]

Workload monitoring is an important strategy that ensures athletes are optimally prepared for competition demands.[8] Monitoring is essentially executed to maximise positive outcomes of training processes such as improved performance and fitness, while reducing non-functional overreaching, fatigue and risk for musculoskeletal injuries or illnesses.[7,8,14] Both over- and under loading have been identified as injury risk factors among fast bowlers.[8–10,15] Fast bowlers who bowl more than 50 (high acute workload) overs in a multi-day test match, are at an increased risk of injury for up to 28 days (odds ratio (OR) =1.62).[16] Furthermore, bowlers who bowl more deliveries in a week (>188 deliveries) and have less recovery between sessions (<2 days) are at greater injury risk compared to those who bowl between 123 and 188 deliveries per week and have 3–3.99 days' recovery between sessions.[10] Bowlers who bowl fewer deliveries each week (<123 deliveries) with more recovery (>5 days) also have an increased risk of injury.[3] Additionally, sudden "spikes" in workload also increase injury risk.[14] Higher chronic workloads offer protection against injury.[14,15] A high, medium term workload, as calculated over a period of three months, is protective against tendon injury.[11]

Three common methods, the fitness-fatigue model, acute:chronic-workload ratio (ACWR) and internal:external-load ratio, are used to analyze training-load data.[7] The ACWR is a model that is commonly used to provide an index of athlete preparedness.[17] It considers the current i.e. acute workload (rolling 7-day workload) and the chronic workload (e.g. rolling 28-day workload). The ideal training stimulus, referred to as the 'sweet spot', is one that maximises net performance potential by having an appropriate training load, while limiting the negative consequences of overtraining including injury, illness, and fatigue.[7] The ideal reported acute/chronic ratio is between 0.8 and 1.3.[7]

While "workload" is a common term in the vernacular of many disciplines, including sport and exercise science, ths use thereof has recently received scruiteny.[18] The consensus statement regarding methods of monitoring athlete "workload",[7] use the term to describe the intensity and volume of athletes' activities during training and match play. In this context however, neither "work" nor "load" refers to the terms' original, scientific, physical properties nor are they expressed in their respective Système International d'Unités (SI-Units), i.e. "joule" and "watt".[18] The descriptions and reporting of exercise and training should make correct use of scientific terms, nomenclature and units.[18] The American College of Sports Medicine (ACSM) suggests the use of the terms frequency, intensity, time, type, volume and progression (P; FITT-VP) for exercise monitoring and prescription.[19] Exercise volume includes exercise intensity, time and frequency. The term "bowling volume" (BV) in this paper refers to number of balls bowled.

While several studies have investigated the relationship between BV and injury risk amongst fast bowlers of varying levels,[10,14,20,21] no research investigating this association among elite South African bowlers has been conducted. Therefore, the purpose of this study was to prospectively monitor BV emposed on fast bowlers playing for the South African national side (the Proteas) and investigate the association thereof to injury risk. Subsequently, acute:chronc BV associated with increased injury risk can be used to quantify risk related to bowlers training and match bowling volumes. Additionally, BV and injury data presented in this paper can be used for seasonal comparisons or comparison to other cohorts, e.g. bowlers of different countries or levels of play.

Methods

Ethical approval was obtained from the tertiary institution's ethical standards committee (RU-HSD-16-11-001). Written informed consent were provided by all players.

Sample size and selection

Fourteen male fast bowlers playing for the South African national side were prospectively monitored from April 2017 to April 2019. Players who were selected to play for South Africa during this period were monitored, and data was continually collected. Players who did not play in both seasons were excluded from the analyses. A fast bowler was defined as a player who bowled more than 10% of the total team overs bowled during matches, and where the wicket keeper stands some distance behind the stumps, compared to directly behind as with slow or medium paced bowlers.[22]

The number of elite level athletes is inherently low. Subsequently small sample sizes with lower statistical power, is common in elite level sports' research.[23] In the case of this study, the intented population is even smaller as a sub-group of elite players, i.e. fast bowlers, were investigated. Furthermore, only bowlers selected to participate in international matches were considered. Specific aspects related to the professional environment further contribute to small sample sizes. These include: an understandable reluctance from coaches and players to accept study-related interference with established routines, and lack of regulatory pressure (compared to for e.g. pharmaceutical trails among athletes).[23]

Data collection – Bowling volume

Players in a cricket team participate in batting, fielding and conditioning activities. Activities specifically related to bowling differentiates fast bowlers from other players, and volumes related to non-bowling activities were therefore not considered. Bowling volume was quanitified as the number of balls bowled during training and competition. Only technical balls bowled i.e. those with a full run-up, were considered. Training BV were self-reported by players. The total number of balls bowled on each day, for each fast bowler, for the period under analysis, were summarised into weekly blocks from Sunday to Sunday. Weeks where no balls were bowled, for example during travel or rest, were also included. Match BV were based on official match statistics. Both match and training BV were logged on an online platform by franschise and national team coaching and medical staff. Researchers had continual access to the online platform and logged volumes were assessed by the national strength and conditioning specialist and the research team for any anomalies or missing data.

Injury surveillance

Injury data were collected and classified by the national and franchise medical personnel. Data added to the online platform by the medical personel were verified by the national strength and conditioning coach. Location of injury, diagnosis, mechanism of injury and mode of onset were recorded by the designated medical personnel. Based on the recommendations by the International Consensus Statement on Injury Surveillance in Cricket,[22] injuries were defined as "any health-related condition that required medical attention and had the potential to affect participation in cricket training or match play".[22] Both time-loss and non-timeloss injuries were included. A general time-loss injury was "any injury (or illness) that resulted in a player being unavailable for match-play, irrespective of whether a match or training session was actually scheduled".[22] Only non-contact injuries with a sudden or gradual onset, associated with a specific cricket-related activity, were included in the analysis.

Statistical analysis

The total number of balls bowled in one-week represented acute BV. Chronic BV was calculated as the four-week rolling average acute BV. The acute:chronic bowling volume ratio (AC-BVR) was calculated by dividing the acute BV by the chronic BV, providing the relative size of acute BV compared with chronic BV. A value of greater than one represents an acute BV greater than chronic BV and vice versa. All BV were transformed using the Z-transformation. Skewness and kurtosis indices were explored and data demonstrated normal distribution. Bowling volume classifications consisting of low through very high were created according to z-scores.[17,24] These classifications are displayed in Table 1.

Table 1. Bowling volume (BV) classifications and boundaries for: (A) Acute BV, (B) Chronic BV, **(C) acute:chronic BV ratios overall.**

		Total balls bowled		
Classification	**Z-score**	**Acute (A)**	**Chronic (C)**	**A:C Ration**
Low	−1.99 to −1.00	0-3	0-26	0.00

Moderate-low	−0.99 to −0.01	9-86	27-90	0.00-0.79
Moderate-high	0.00 to 0.99	88-170	91-154	0.80-1.60
High	1.00 to 1.99	172-254	155-218	1.62-2.43
Very high	≥2.00	256-400	219-264	2.48-4.00

Null-hypothesis testing was conducted using a binomial generalised mixed model with injury or no injury as the dependent variable. Acute BV, chronic BV, and acute:chronic BV ratios were independently modelled as predictor variables. Each player was included as a random effect to control for individual variation in response to injury risk and bowling volume. Separate models were not constructed for each injury type due to a small sample size. If they were to be separated, the model would produce unstable outcomes, and the accuracy would be further compromised. A receiver operating characteristic curve (ROC) and the area under the curve (AUC) were calculated to provide a performance measure of the model. Relative risk (RR) were calculated to determine which BV variables increased (RR >1.00) or decreased (RR<1.00) the risk of injury.[25] For a RR to be significant, 95% confidence intervals (CIs) did not contain the null RR of 1.00. The statistical software R® (Version 1.0.153) was used for all analyses. Due to the small sample size, all significance thresholds were set at 0.05.

Results

Fourteen fast bowlers sustained a total of 39 medical attention, non-contact injuries during the period under review. The majority of injuries (58.97%, n=23) were timeloss injuries. The most frequently injured body area was the lumbar spine (25.64%) followed by the hip and groin (17.95%). The areas of injury are shown in Table 2.

Table 2: Breakdown of injury by type and specific regions.

	Injury episodes by specific region		
Body area of injury	**Non-time-loss injuries n**	**Time-loss injuries n**	**Medical attention injuries n (%)**
Shoulder	0	2	2 (5.13)
Cervical spine	2	0	2 (5.13)
Trunk and abdominal	1	3	4 (10.26)
Lumbar spine	**2**	**8**	**10 (25.64)**
Hip and groin	2	5	7 (10.26)
Anterior thigh	2	0	2 (5.13)

Posterior thigh	1	2	3 (7.69)
Knee	2	0	2 (5.13)
Lower leg	2	1	3 (7.69)
Ankle	2	1	3 (7.69)
Foot	0	1	1 (2.56)
Total	**16**	**23**	**39 (100)**

The relationship between each workload classification and relative risk of injury is shown in Table 3 and Figure 1.

Table 3. Bowling volume classification and risk of injury.

Bowling volume	**Mean±SD**	**p-value**	**AUC**	
Acute	87.21±83.86	0.16	-	
Chronic	90.18±64.55	0.01*	-	
Acute:chronic ratio	0.80±0.82	0.55	-	
			0.63	
		95% CI		
Classification	**RR**	**2.5%**	**97.5%**	**p-value**
Acute				
Low	1.03	1.01	1.04	0.01*
Moderate-low	0.99	0.96	1.01	0.32
Moderate-high	0.98	0.96	1.00	0.07
High	1.00	0.98	1.03	0.99
Very High	1.01	0.97	1.05	0.99
Chronic				
Low	1.03	1.02	1.05	0.001*
Moderate-low	1.00	0.98	1.02	0.99
Moderate-high	0.98	0.96	0.99	0.02*
High	0.99	0.96	1.02	0.40
Very High	1.03	1.02	1.04	0.99
Acute: chronic ratio				
Low	-	-	-	-
Moderate-low	1.00	1.01	1.02	0.02*
Moderate-high	0.99	0.97	1.01	0.43
High	1.00	0.97	1.04	0.99
Very High	1.03	1.02	1.04	0.26

Chronic BV was a significant predictor of injury occurance (z = 2.82, p = 0.01). A low acute BV (RR= 1.03, 95% CI[1.01;1.04], p = 0.01), low chronic BV (RR= 1.03, 95% CI[1.02;1.05], p = 0.001), moderate-high chronic BV (RR= 0.98, 95% CI[0.96;0.99], p = 0.02) and moderate-low acute:chronic ratio (RR= 0.98; 95% CI[1.01;1.02], p = 0.02) demonstrated a significant risk of injury.

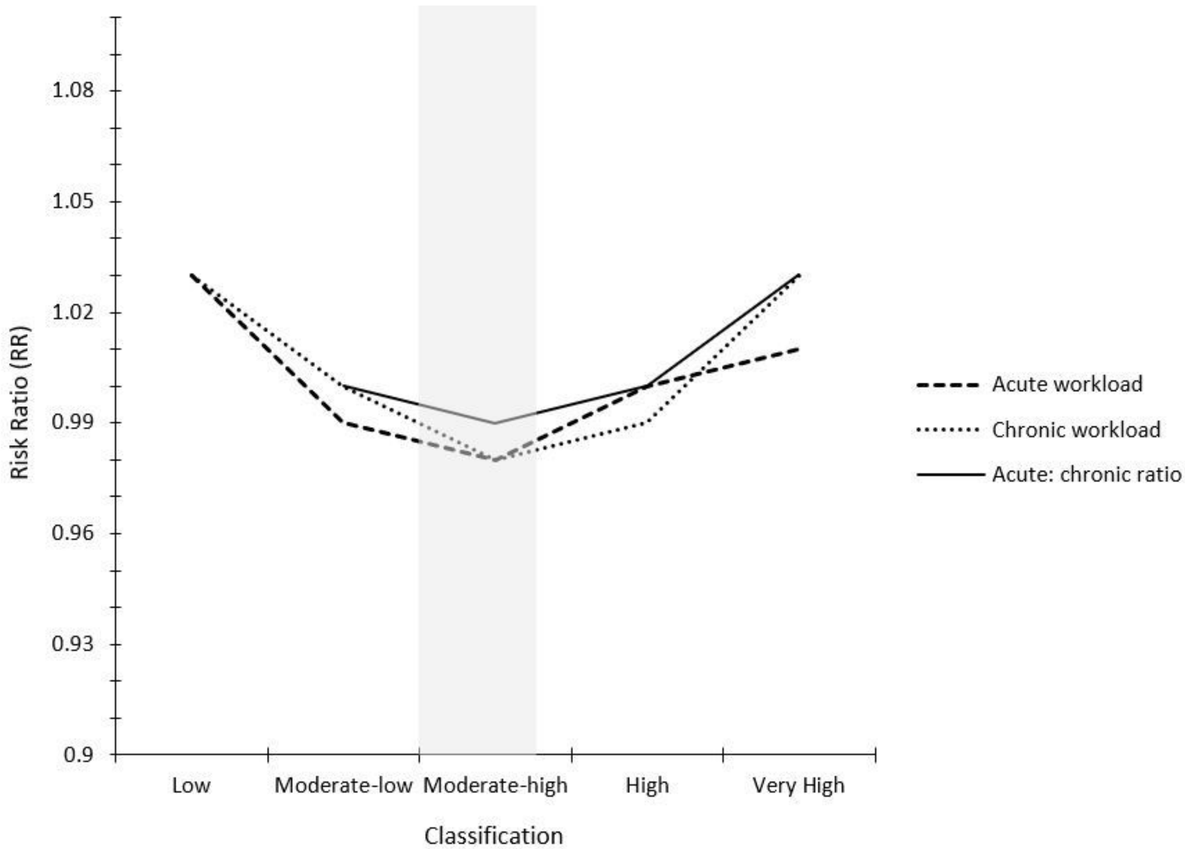

Figure 1. Relationship between BV classification and relative risk of injury in elite fast bowlers. Grey highlighted area indicates the "sweet spot" for acute: chronic ratio.[25]

Discussion

While aiming at generalisable inferences regarding the BV-injury association among Protea fast bowlers, practically the focus of this research was also to provide coaching, conditioning and medical staff with data related to specific players. The most important finding of this study was that there was a reduced risk of injury between a moderate-to-low and a moderate-to-high acute:chronic BV ratio (i.e. A:C Ratio = 0:00-1.60).

Most injuries were to the lumbar spine (n=10, 25.64%) followed by the hip and groin which is comparable to the findings of a study done on West Indies pace bowlers who reported 21 injuries over a seven month period with the majority of injuries sustained to the lumbar spine, followed by the lower limbs.[26] Similarly, in an Australian study, lower limb injuries, including hip and groin injuries, were the most common, followed by lumbar spine injuries.[9] Low back injuries such as vertebral bone stress injuries are common in sports that require activities with repetitive flexion, extension and rotation including gymnastics and baseball pitching.[16,27,28] The cricket bowling action requires additional contralateral trunk side flexion which coincides with high front foot vertical reaction forces further exposing bowlers' lumbar spines to repetitive impact type injuries.[27,28]

We found no significant differences between acute, chronic and acute:chronic BV ratio as predictors of injury occurance. However, when BV were categorised, it was found that low chonic workload and moderate-low acute:chronic BV ratios demonstrated a small, yet significant increased injury risk in elite fast bowlers compared to the other BV thresholds. Even though non-significant; low, high and very high acute, chronic and acute:chronic ratios also demonstrated an increased risk in injury. These findings support the notion that BV and injury risk have an U-shaped relationship.[29] However these findings are tentative as this study focused on elite players and therefore yielded a small sample size, and consequently an insufficient number of injury records of a particular type (medical assistance and time loss) to create different injury specifc models and determine relative risk.

There was a decreased risk of injury between a moderate-low (0.00-0.79) and moderate-high (0.8-1.6) acute:chronic BV ratio, which is partially congruent with the 0.8-1.3 threshold.[7,29] Potentially, fast bowlers in the current study who achieved a moderate-high chronic BV (91-154 bowled balls) may have improved the physical qualities associated with decreased injury risk (RR= 0.98). Additionally, sport practitioners recognise extreme fatigue, and low levels of fitness to be significant factors that increase rick of injury in team sport athletes.[30] When considering our findings, players who were training at a moderate-high acute:chronic BV ratio had an acute BV (88-170 bowled balls) similar in size to their chronic BV (91-154 bowled balls). This tentatively indicates that moderate-high chronic and acute:chronic ratios were associated with a decreased injury risk, which may potentially suggest that a moderate-high acute:chronic BV ratio combined with a moderate-high chronic BV (i.e high 'fitness') would be associated with a lower risk of injury than a moderate acute:chronic BV ratio combined with a low chronic workload (i.e low 'fitness'). The findings of this study further demonstrated that low absolute BV were associated with a non-significant increased injury risk, which contrasts the findings of other studies.[14,17,31] However, only looking at ratios could be misleading and these should be considered with absolute volumes. Further, this may indicate that bowling conditioning needs to be more specific.

The model classification suggests that acute, chronic and acute:chronic ratios are limited in their ability to predict injury occurrence (AUC = 0.63). This level of performance was similar to other modelling studies in rugby league (AUC=0.64-0.74)[32] and Australian Football (mean AUC< 0.7).[33] However, more data is needed to ensure more stability and accurate results. Further, as ony a few injuries occurred during the given time frame, the accuracy and stability of the model outcomes were compromised. Accumulating more player BV and injury data (> 10 seasons) may be necessary to construct practically useful and accurate prediction models.[33]

Nonetheless, this not does not rule out training volume monitoring and management as a valid practice as there is strong evidence that spikes in acute:chronic BV ratios are associated with increases in team injury rates.[14,29,34–36] Therefore, measuring absolute and relative training volumes in team sports to monitor volume progression and allow for informed modification of training schedules is still considered best practice.[36]

Conclusion

This study is the first to describe the bowling volumes placed on fast bowlers playing for the South African national side (the Proteas) and to link these volumes to injury risk. Chronic BV was a predictor of injury occurrence while a low acute BV, a low chronic BV, a moderate-high chronic BV and moderate-low acute:chronic ratio demonstrated a significant risk of injury. These findings support the notion that bowling volume and injury risk have a U-shaped relationship.

Practical Implications

- Monitoring bowling volume is still considered best practice.
- Low bowling volumes (both acute and chronic) increase injury risk.
- A moderate-high acute:chronic bowling volume ratio combined with a moderate-high chronic bowling volume is best for injury reduction.
- Bowling specific conditioning is important for reducing injury incidence.

Conflict of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions

Authors CC and LP have given substantial contributions to the conception or the design of the manuscript, author GK, ALR, BO, KM, CEM, BJ and SM to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript, author CM revised it critically. All authors read and approved the final version of the manuscript.

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