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Abstract

Background: Although many cricket-playing nations have conducted research on bowling volume (BV) and injury risk, this relationship amongst international South African pace bowlers is yet to be investigated. Environmental, socio-economic and training strategy differences warrant similar research in a South African context. The purpose of this preliminary study was to establish whether South African pace bowlers have similar BV and injury associates compared to other elite fast bowlers.
Methods: This study was a prospective, observational, cohort study that monitored match and training BV and injuries amongst pace bowlers playing for the South African national team between April 2017 and April 2019. A sample of convenience that included 14 bowlers was selected. Bowling volume was quantified as the number of deliveries bowled during training and competition. Acute-, chronic- and acute:chronic BV ratios were independently modelled as association variables.
Results: There were 39 injuries with the most being to the lumbar spine (25.64%). Moderate-to-low and a moderate-to-high acute:chronic bowling load ratios were associated with a lower risk of injury. Chronic bowling load was associated with injury ($z = 2.82$, $p = 0.01$). A low acute workload, low chronic workload, moderate-high chronic workload and moderate-low acute:chronic ratio were also associated with an increased risk of injury.
Conclusion: These findings confirm that there appears to be a dose–response effect between training BV and the likelihood of an injury occurring with a moderate-to-low and a moderate-to-high BV ratio being optimal. Considering the small sample size, the findings should be interpreted with caution.

Keywords

Acute:chronic workload ratio, lumbar spine, training

Introduction

Pace bowlers endure greater physical demands and external workload requirements than other players (batters, spin bowlers and wicketkeepers) on a cricket team.[1,2] Irrespective of match format, pace bowlers cover 20–80% greater distances, exert 2–7 times higher intensity in terms of running speeds (ie., >4 m/s) and have 35% less recovery time between high-intensity efforts.[1,2] Additionally, pace bowlers are at greater risk 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 pace bowling action further exposes players to injury. This action requires an awkward combination of lateral lumbar spine flexion, extension and rotation, whilst absorbing forces as high as 8 times their body mass during the delivery stride.[4–6]

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A holistic depiction of players' workload requires measuring 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 measures such as distances covered.[7,8] Internal stressors include the physiological and psychological stress imposed on players in response to external stress and can be measured objectively (e.g., heart rate variability, resting heart rate or blood lactate) or subjectively (e.g., session rate of perceived exertion [sRPE]).[7] Higher absolute workload amongst pace 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 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 underloading have been identified as injury risk factors amongst pace bowlers.[8,15,16] Pace 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 = 1.62).[15] 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.[14,16] Bowling load also affects the risk of sustaining injuries to specific structures differently.[11] Very high acute match workload (7 days >50 overs) and a high previous season workload (>400 overs) are risk factors for developing tendon injuries, but a high medium-term workload (3-month workload >150 overs) seems to be protective.[11] Workload in the previous 3 months, however, has the opposite effect on risk for bone injuries than for tendon injuries, that is, the high workload in the previous 3 months is a risk for stress fractures but protective against tendon injuries.[11]

Methods used to analyse training load amongst athletes include the fitness-fatigue model, acute:chronic-workload ratio (ACWR), internal:external-load ratio[7] and differential load.[17] The ACWR is a model commonly used to provide an index of athlete preparedness.[18] Impellizzeri et al.[19] highlight several limitations related to the ACWR's direct causal effect on athletes' injury risk. However, the ACWR has been associated with increased injury risk amongst various athletes.[18,20–22] Considering the associations between the ACWR and, specifically, injuries amongst pace bowlers,[14,20,23] this model was used for analysis in this study. It considers the current, that is, acute workload (e.g., rolling 7-day workload) and the chronic workload (e.g., rolling 28-day workload). The ideal training stimulus, referred to as the 'sweet spot,' 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]

Although many cricket-playing nations have investigated the relationship between bowling volume (BV) and injury risk amongst pace bowlers of varying levels,[10,14,23,24] no research investigating this association amongst international South African bowlers has been conducted. Compared to other countries, South Africa has several potential environmental, socio-economic, training and match strategy differences. Additionally, differences in bowlers' anthropometric and physical characteristics[25] warrant similar research in a South African context. Therefore, the purpose of this preliminary study was to establish whether international South African pace bowlers have similar BV and injury associates compared to other elite fast bowlers. Bowling volume and injury data presented in this paper can be used for seasonal comparisons or comparisons to other cohorts, for example, bowlers of different countries or levels of play. Ultimately, findings of this and continued future research can be used to develop BV guidelines to identify bowlers at risk of sustaining injuries and to assist and inform coach/manager decision-making on bowlers' availability for training and match play.

Methods

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

Sample size and selection

Fourteen male pace bowlers playing for the South African national side, regardless of the game's format, were prospectively monitored from April 2018 to April 2019. Although a longer time period would have been more optimal, the 2019–2021 seasons were irregular due Covid-related training and match disruptions. This paper, therefore, reports the preliminary findings of an ongoing longitudinal study amongst bowlers included in the South African national team. In total, data from 21 test matches, 36 ODI's and 18 T20 matches were included. Over the period of data collection, the total number of match and practice deliveries from all formats were pooled by the player management system used for data collection. The athlete management system does not distinguish between bowling workload during domestic and international matches or practice and match deliveries, respectively.

At different professional levels of play, for example, domestic versus international level, differences in the intensity and frequency of bowling and therefore, overall BV, exist.[26]

Therefore, only players selected to play for the South African national team during this period were monitored, and data were continually collected. Only data for players who played in both seasons were included in the analyses, as these players were the main bowlers for the national side during the data collection period and most consistently included national team. The inclusion of data from players who only played one or two matches for the national side during one of the seasons would have skewed results. The inclusion criteria for each player to be deemed international were, therefore, that they needed to represent the national side for at least one game during the data collection period in both seasons (2017–2018 and 2018–2019).

A pace bowler was defined as a bowler who bowled more than 10% of the total team overs bowled during matches and where the wicketkeeper stands some distance behind the stumps, compared to directly behind as with spin bowlers.[27] Small sample sizes with lower statistical power are common in elite-level sports research.[28] At an international level, cricket teams, usually include an average of four specialist bowlers. In the case of this study, the intended population is even smaller as a sub-group, that is, pace bowlers were investigated.

Definition and data collection – BV

Although 'workload' is a common term in the vernacular of cricket research that investigates the volume and intensity of specific cricket-related activities players are exposed to, the use thereof has recently received scrutiny.[29] 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), that is, 'joule' and 'watt'.[29] The term 'bowling volume' (BV) is, therefore, used throughout the remainder of this paper and refers to the number of balls bowled during training and competition.

Activities specifically related to bowling differentiate pace bowlers from other players, and volumes related to non-bowling activities were, therefore, not considered. Only technical balls bowled, that is, those with a full run-up were considered. All the overs players bowled in the season were included (i.e., domestic and international matches & training). Training BV was self-reported by players. The total number of balls bowled each day, for each pace 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 was based on official match statistics. Both match and training BV were logged on an online platform by franchise (domestic or team other than the national team bowlers played for) 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 team's medical personnel. Data added to the online platform by the medical personnel 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,[27] 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'.[27] Both time-loss and non-time-loss 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 scheduled'.[27] Only non-contact injuries with a sudden or gradual onset, associated with a specific cricket-related activity, that is, sustained during a scheduled training session or match, were included in the analysis.

Statistical analysis

Acute BV represents the total number of balls bowled during one week (7 days). Chronic BV was calculated as the 4-week rolling average acute BV. The acute:chronic BV ratio (AC-BVR) was calculated by dividing the acute BV by the chronic BV, providing the relative size of acute BV

Table 1. Bowling volume (BV) classifications and boundaries for: (A) Acute BV, (B) Chronic BV and (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

compared with chronic BV. A value 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.[18,20] These classifications are displayed in Table 1.

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 AC-BVRs were independently modelled as association variables. Each player was included as a random effect to control for individual variation in response to injury risk and BV. 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 and the area under the curve (AUC) were calculated to provide a performance measure of the model. Relative risk (RR) was calculated to determine which BV variables increased (RR > 1.00) or decreased (RR < 1.00) the risk of injury.[30] For a RR to be significant, 95% confidence intervals did not contain the null RR of 1.00. The statistical software R® (Version 1.0.153) was used for all analyses. All significance thresholds were set at 0.05.

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 (100.00)

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

Results

Fourteen pace bowlers sustained 39 medical attention, non-contact injuries during the period under review. The majority of injuries (58.97%, $n = 23$) were time-loss 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.

Discussion

Although many cricket-playing nations have investigated the relationship between BV and injury risk amongst pace bowlers,[10,14,23,24] this is the first study investigating this association amongst South African national side pace bowlers. The most important finding of this study was that a moderate-to-low and a moderate-to-high AC-BVR (i.e., A:C Ratio = 0:00–1.60) was associated with a lower risk of sustaining injuries. Conversely, amongst English and Welsh first-class cricket pace bowlers, an ACWR (1.09–1.42) that falls within the above-mentioned ACWR range increased bowlers' injury risk.[23] The difference in

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	0.00*
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 bowling volume (BV) was associated with an increased risk of sustaining an injury ($z = 2.82$, $p = 0.01$). A low acute BV (relative risk [RR] = 1.03, 95% confidence interval [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.

results could be attributed to factors including the difference in the level of play (i.e., first-class vs. international level), environment (South Africa vs. England/Wales) and larger sample size (39 bowlers). These results demonstrate the importance of adapting rather than fully adopting available evidence-based practices and validating the adapted practices in a specific team.[7] Like this current study, significant individual differences in the acute:chronic workload–injury relationship were evident amongst the English and Welsh fast bowlers. Although aiming at generalisable inferences regarding the BV-injury association amongst South African national team pace bowlers, practically the focus of this research was to provide coaching, conditioning and medical staff with data related to specific players.

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 7-month period, with the majority of injuries sustained to the lumbar spine, followed by the lower limbs.[31] Similarly, in an Australian study, lower limb injuries, including hip and groin injuries, were the most common, followed by lumbar spine injuries.[9] Lumbar bone stress injuries (LBSI) are common in sports that require activities with repetitive flexion, extension and rotation, including pace bowling, gymnastics and baseball pitching.[15,32,33] 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.[32,33] However, several kinematic and kinetic technique parameter differences related to the lumbo-pelvi-femoral complex predispose some bowlers to LBSI more than others.[34] Due to the relatively small number of injuries in this study, subgroup analysis of the BV–lumbar injury relationship would not yield meaningful results. However, bowlers' BV should be considered with technique and other identified risk factors when developing strategies to mitigate lumbar injuries amongst pace bowlers.

We found no significant differences between acute, chronic and AC-BVR and injury incidence. However, when BV was categorised, it was found that low chronic workload and moderate-low AC-BVRs demonstrated a small yet significant increased injury risk in elite pace 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 of injury. These findings support the notion that BV and injury risk have a U-shaped relationship,

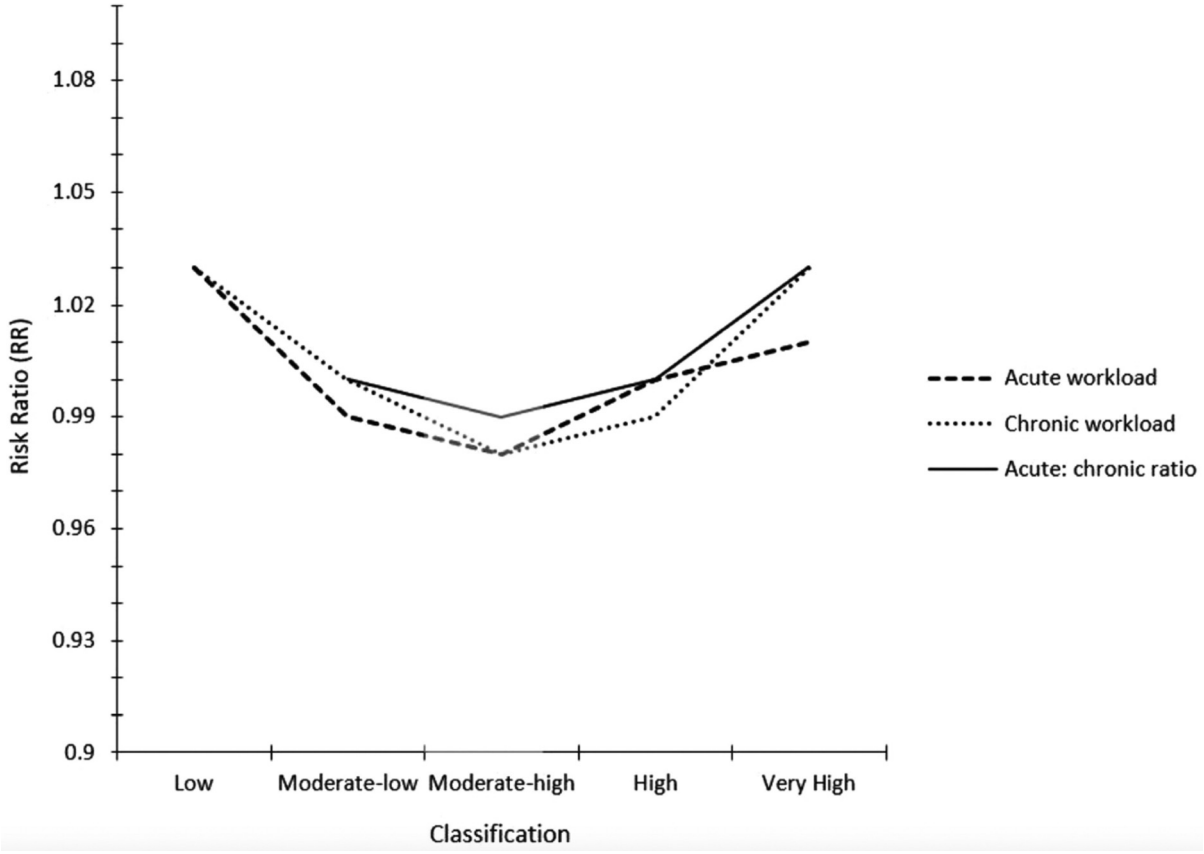


Figure 1. Relationship between bowling volume (BV) classification and relative risk of injury in elite pace bowlers. Grey highlighted area indicates the 'sweet spot' for acute: chronic ratio.[25]

indicating that the lowest incidence of injury is in the middle ranges (moderate-high acute, chronic and acute-chronic workload ranges), with peaks in both the lower and upper ranges.[35] This confirms that both undertraining and over training can increase the risk of injury by impacting training adaptations, fitness and fatigue, respectively.[8] However, these findings are tentative as this study focused on players selected for the national team and yielded a small sample size. Consequently, an insufficient number of injury records of a particular type (medical assistance and time loss) to create different injury-specific models and determine RR.

There was a decreased risk of injury between moderate-low (0.00–0.79) and moderate-high (0.80–1.60) AC-BVR, which is partially congruent with the 0.80–1.30 threshold.[7,35] Potentially, pace 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, sports practitioners recognise extreme fatigue and low levels of fitness to be significant factors that increase the risk of injury in team sport athletes.[36] When considering our findings, players training at a moderate-high AC-BVR 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 AC-BVR combined with a moderate-high chronic BV (i.e., high 'fitness') would be associated with a lower risk of injury than a moderate AC-BVR combined with a low chronic workload (i.e., low 'fitness'). The findings of this study further demonstrated that low absolute BV was associated with a non-significant increased injury risk, which contrasts with the findings of other studies.[14,18,21] 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 association to injury incidence is limited (AUC = 0.63). This level of performance was similar to other modelling studies in rugby league (AUC = 0.64–0.74)[37] and Australian Football (mean AUC < 0.70).[38] However, more data are needed to ensure more stability and accurate results. Further, as only 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 injury risk models.[38] Methodological concerns and limitations of the ACWR model have, however, been raised.[17,19] The differential training load, that is, a smoothed week-to-week rate change in load, has been proposed as an alternative to the ACWR and found useful to identify spikes in training volume and, subsequently, injury amongst first-class county cricketers.[17] Considering the difference in frequency and intensity of BV of national-level players, the usefulness thereof amongst different level cricketers is yet to be determined. The lack of consensus amongst previously and newly proposed models for analysing pace bowlers' training volume warrant continued research to establish the most appropriate practices.

Nonetheless, this does not rule out training volume monitoring and management as a valid practice, as there is strong evidence that spikes in AC-BVRs are associated with increased team injury rates.[14,22,35,39,40] Therefore, measuring absolute and relative training volumes in team sports to monitor volume progression and allow informed modification of training schedules should still be considered.[40] Although longitudinal research with larger sample sizes and longer observational periods would provide a more holistic depiction of the pace BV–injury relationship, the findings of this study can be used as a starting point for the development of conditioning programmes and decision-making guidelines related to South African pace bowlers.

This study was not without limitations. Due to the small sample size, results should be interpreted with caution. The intensity with which balls were bowled was not included as a BV variable. The bowling intensity would impact potential injury risk if bowlers were, for example, not performing at match-like intensity for periods of time outside of matches. Future research should, therefore, include a measure of intensity (e.g., players' reported sRPE)[41] when investigating BV. Although the strength and conditioning coaches verified the accuracy of bowlers' reported number of deliveries after training sessions, delegating real-time observational surveillance to a specific person would be more optimal. Distinguishing between match and training data at international and domestic level as opposed to pooled data per player could have provided more context for the interpretation of the results. Considering the multifactorial nature of pace bowling injuries, future research should analyse BV with other known injury risk factors to establish multi-variant risk models.

Conclusion

This study is the first to describe the BVs placed on pace bowlers playing for the South African national side and to link these volumes to injury risk. Chronic BV was associated with injury risk, while a low acute BV, a low chronic BV, moderate-high chronic BV and moderate-low acute:chronic ratio demonstrated a significant association with injury risk. These findings support the notion that BV and injury risk have a U-shaped relationship.

Practical implications

- Monitoring BV is still considered a useful practice.
- Low BVs (both acute and chronic) increase injury risk.

- A moderate-high AC-BVR combined with a moderate-high chronic BV is best for injury reduction.
- Bowling-specific conditioning is important for reducing injury incidence.

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Authors' contribution

CC and LP have given substantial contributions to the conception or the design of the manuscript. 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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