Abstract

Context: Cricket fast bowlers are particularly susceptible to lumbar spine loading and injury. Quantitative analysis of technique typically involves laboratory-based biomechanical systems with limited ecological validity, whereas contemporary developments in GPS microtechnologies facilitate on-field evaluation of loading. ***Objective:*** To quantify the influence of sub-maximal bowling from reduced approach lengths on performance and loading. ***Design:*** Repeated measures, field-based. ***Setting:*** Regulation cricket pitch. ***Participants:*** 12 male cricket academy fast bowlers (18.7 ± 0.7 y), injury free with ≥3 years competitive experience. ***Interventions:*** Each bowler wore 2 GPS units placed at C7 and L4 to measure triaxial acceleration (100 Hz). Bowlers completed an over (six deliveries) from a randomised 3, 6, 9, and 12 stride approach. ***Main Outcome Measures:*** Ball speed was recorded as the performance measure, with PlayerLoad in the anteroposterior, mediolateral and vertical planes also calculated for each delivery length. ***Results:*** In ball speed there was a significant main effect for delivery length ($P = 0.016$), with a 3 stride approach eliciting significantly less ball speed than a 9 ($P = 0.032$) or 12 ($P = 0.002$) stride approach. In loading, there was a significant ($P < 0.001$) main effect for delivery length in the anteroposterior, mediolateral, and vertical planes, with loading increasing linearly as a function of delivery strides. The 6 stride approach elicited a 44% reduction in loading, with a disproportionately small 3.5% decrease in performance. There was a significant main effect for GPS location in all planes ($P \leq 0.023$), with L4 eliciting greater loading than C7. ***Conclusions:*** A sub-maximal 6 stride approach yielded the optimum balance between reduced loading and performance inhibition. Reduced delivery length therefore offers an alternative to reduced overs in reducing loading in young bowlers, and might also have practicable value in the rehabilitation of bowlers post-injury.

Introduction

Epidemiological research in cricket has highlighted the risk associated with fast bowling, accounting for up to 66% of all injuries[1] and with an annual injury prevalence of 20.6%.[2] Lumbar stress fractures are the most prevalent injury, accountable for 15% of missed playing time.[2] The fast bowling action is characterised by repetitive lumbar flexion, rotation and hyperextension,[3] increasing the risk of injury to the spine. The action is complex and multi-axial, with transverse plane counter-rotation of the shoulders relative to the hips,[4] and contra-lateral lumbar side-flexion.[5] Lumbar flexion torques exceeding 700Nm have been quantified during ball release in laboratory-based studies,[6] but the methodological approach has limited ecological validity and practical application in a rehabilitation context. Injury prevention strategies have instead considered 'loading' with respect to the volume of overs performed, targeting bowling workload as the primary modifiable risk factor for injury.[7,8] Bowling in excess of 50 overs in a 5 day period,[7] or with a rest period of less than 2 days between bowling sessions [8] significantly increased the risk of subsequent injury. In response, the England and Wales Cricket Board (ECB) issued a directive that players up to the age of 13 years bowl a maximum of 10 overs (in 2 spells) per day, increasing to a maximum of 18 overs (in 3 spells) for players up to 19 years.[9] However, a laboratory-based intervention study showed no change in lumbar segment kinetics during an 8 over bowling spell,[10] consistent with a recent study which quantified loading using a PlayerLoad metric derived from tri-axial accelerometry.[11] Greig and Nagy suggested that if workload restriction guidelines are too conservative then they might actually impair workload tolerance and technical development in young fast bowlers.[11]

In the current study workload is modified by varying the number of delivery strides, as a practical alternative to simply reducing the number of overs bowled. Whilst there are six deliveries in each over, there is a great deal of variation amongst elite bowlers in terms of the length of the delivery. The number of delivery strides has also been influenced by the evolution of different forms of cricket (such as limited overs competitions).[2,7] A 'sub-maximal approach' has previously been investigated in athletic high jumping, where a 15% reduction in approach speed resulted in only a 3% decrease in jump height.[12] This reduction in approach speed was achieved by manipulating the number of approach strides taken,[12] which is typically self-selected. This is analogous to cricket fast bowling, where the performance outcome would be ball release speed, whilst acknowledging a need to retain accuracy. McNamara et al. recently commented that bowling at faster velocities is likely to require greater effort and place greater load on the bowler.[13] However, if ball speed can be retained from a shorter delivery, then loading on the bowler could be reduced. If this translates to reduced loading in the lumbar region then sub-maximal bowling could become a viable means of manipulating bowling loads in relation to a periodised conditioning programme and in the rehabilitation of fast bowlers post-injury. McNamara and colleagues highlighted the potential for wearable microtechnology devices as a means of prescribing and monitoring bowling workload.[13,14]

The microtechnology described typically refers to a tri-axial accelerometer embedded within a global positioning satellite (GPS) unit. This unit is typically worn in a customised vest which positions the accelerometer at approximately C7, a location primarily based upon enhancing satellite reception for the GPS-derived analysis metrics. The prevalence of lumbar injuries in fast bowlers,[1,2] and the multi-axial nature of the injury mechanism,[3-5] were used recently to justify a comparison of mechanical loading (based on the rate of change of acceleration) at the lumbar and cervical spine using two GPS units.[11] In the current study, the influence of approach length on performance (quantified as ball release) and load (measured at C7 and L5) was measured to investigate the potential for sub-maximal bowling to reduce injury risk.

Methods

Design

The study was a repeated-measures design. To increase the ecological validity of our study, all analyses were conducted on a regulation cricket pitch with participants tested in a single session. The number of approach strides in each delivery and the location of the GPS unit were the independent variables. The PlayerLoad in each of the tri-axial planes and ball release speed were the dependent variables. Subsequently, the relative contribution of each uni-axial plane to total PlayerLoad (defined as the sum of the three uni-axial planes) was quantified.

Participants

Fast bowlers were recruited from an elite cricket academy. Inclusion criteria required that participants had a minimum 3 years bowling at a competitive level, had no previous injuries in the 6 months prior to testing, and no history of chronic low back pain (defined as exceeding 3 months in duration). At the time of testing all bowlers were competing in club and county-level cricket with a training status equivalent to one match and three training sessions per week. Testing was conducted during the competitive season to ensure an appropriate level of conditioning, with weekly bowling volume not exceeding that defined by governing body guidelines.[9] In total, 12 bowlers completed the study (18.7 ± 0.7 yrs). All bowlers provided written consent, and the project was approved by the departmental research ethics committee, in accord with the Helsinki Declaration.

Procedures

All bowling trials were completed using a regulation cricket crease (22 yd, ~20 m), with wicket at either end. Participants were fitted with 2 GPS-mounted tri-axial accelerometer units (Catapult MinimaxX S4, Catapult Innovations, Scoresby, VIC, Australia). The first unit was placed in a customised vest and worn by the participants per manufacturer's guidelines, positioned at approximately C7. The second unit was fixed (using underwrap tape [Mueller Sports Medicine Inc, Prairie Du Sac, WI, USA]) to the lumbar spine at approximately L4.[11] Data were collected using Catapult MinimaxX GPS-mounted tri-axial accelerometers. Uniaxial acceleration was collected at 100 Hz in the mediolateral (ML), anteroposterior (AP), and vertical (V) planes.

Two speed guns were utilised to quantify ball speed ($km \cdot h^{-1}$), suggested to be the gold standard methodology to use alongside GPS for speed with regards to validity.[15] One speed gun was placed 5m behind the bowling crease, and the other behind the stumps at the batting crease.[13]

Before data collection, bowlers completed a warm-up designed to replicate their typical match-day routine. Bowlers were instructed to attempt to hit the stumps by bowling a good length each delivery. These instructions defined a target zone familiar to the bowlers, and specifically an area between 3-6m from the batsman's crease, and 1.3m either side of the stumps. A 'wide' delivery was penalised by having the bowler perform an additional delivery, consistent with competition and training practice. Participants bowled in pairs to further enhance ecological validity, and to standardize the rest interval between overs. Between overs, the subjects undertook passive recovery to simulate typical rest periods seen during competitive cricket. An over is classified as a bowler delivering six legitimate balls. In this study participants were required to complete four overs, comprising one over from each of 3, 6, 9, and 12 delivery strides. Each over was completed as a series of six deliveries of consistent stride length to replicate training and competition practice. Whilst stride length was standardised within each over, the order in which the bowler completed these overs (3, 6, 9 or 12 strides) was randomised. The prescribed order of the four overs (defined by delivery length) was allocated using a random number generator for each bowler. The longest delivery of 12 strides was selected as representing the shortest full-length delivery of the bowlers, with the longest delivery reported as 16 strides. This negated the requirement for some bowlers to perform a longer delivery than is their norm. To ensure familiarisation, the 3-12 stride approaches were completed in a minimum of three training sessions prior to the testing session. Subsequently, during the testing session each participant marked out their run up for each delivery length during the warm-up. Warm-up trials (including no ball release) and two practice trials at each delivery length were completed prior to testing.

Statistical analysis

All deliveries were included in the statistical analysis, but for clarity data are subsequently presented as mean ± SD across each delivery length and for each anatomical placement. PlayerLoad in each axial plane is expressed in arbitrary units, defined as the total accumulated body load in each plane and calculated based on the rate of change of acceleration in each plane.[8,9,11] Ball speed is reported as kilometres per hour ($km \cdot h^{-1}$). A general linear model repeated-measures ANOVA was conducted to quantify main effects in GPS location and delivery length. A location *x* delivery length interaction was also examined. The assumptions of normality associated with the general linear model were assessed using the Shapiro-Wilk test to ensure model adequacy, with none of the variables violating any of the assumptions. Where significant main effects or interactions were observed, post-hoc pairwise comparisons with a Bonferroni correction factor were applied. Statistical significance was accepted at $P \leq 0.05$, and main effects were supported with partial eta squared (η^2) calculated as a measure of effect size and classified as small (≤ 0.059), moderate ($0.060 - 0.137$), and large (≥ 0.138). All statistical analysis was completed using PASW Statistics Editor 22.0 for Windows (SPSS Inc., Chicago, IL, USA)

Results

Figure 1 summarises the influence of approach length on ball release speed quantified at the bowler's end (Bo) and batter's end (Ba) of the crease. There was a significant main effect for number of approach strides on ball release speed (*P* = 0.016; η^2 = 0.210). Post-hoc analysis revealed that velocity was significantly impaired from a 3 stride approach relative to a 9 stride (*P* = 0.032) or 12 stride approach (*P* = 0.002). There was also a significant main effect for speed gun location with the speed at Bo greater than Ba (*P* = 0.001; η^2 = 0.353), but no interaction between speed gun location and approach length (*P* = 0.918; η^2 = 0.006).

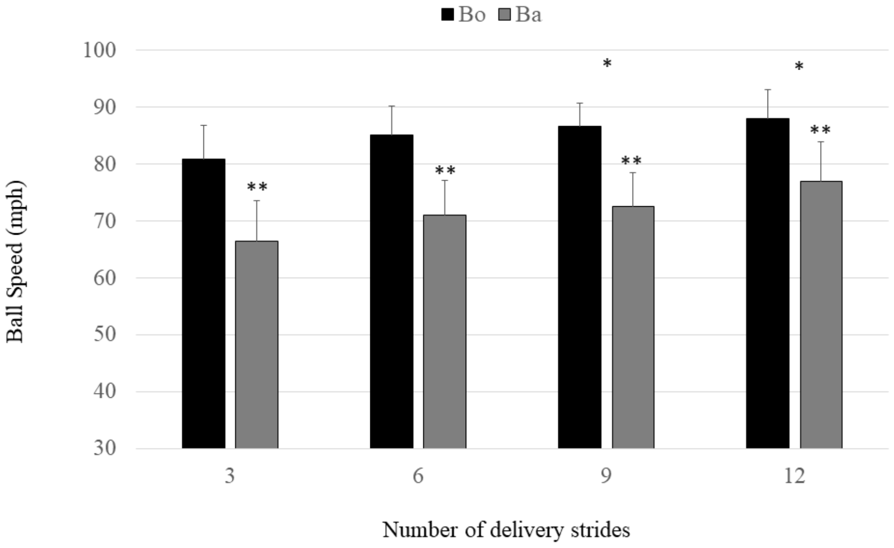

Figure 1. The influence of delivery length on ball speed. * denotes significantly greater than 3 stride approach; ** denotes Ba significantly lower than Bo.

Figure 2 summarises the influence of approach length and GPS unit on accumulated uni-axial PlayerLoad. There was a significant main effect for number of approach strides in AP ($P < 0.001$; $\eta^2 = 0.597$), ML ($P < 0.001$; $\eta^2 = 0.619$), and V ($P < 0.001$; $\eta^2 = 0.558$) PlayerLoad. Post-hoc analyses revealed that each delivery length was significantly different to all others ($P \leq 0.001$), and in all planes, such that uni-axial PlayerLoad increased as a function of stride length.

There was also a significant main effect for GPS location in the AP ($P = 0.023$; $\eta^2 = 0.057$), ML ($P < 0.001$; $\eta^2 = 0.207$) and V ($P = 0.001$; $\eta^2 = 0.117$) planes, with loading greater at L4 than C7 in all planes. There was no location *x* strides interaction ($P \geq 0.25$)

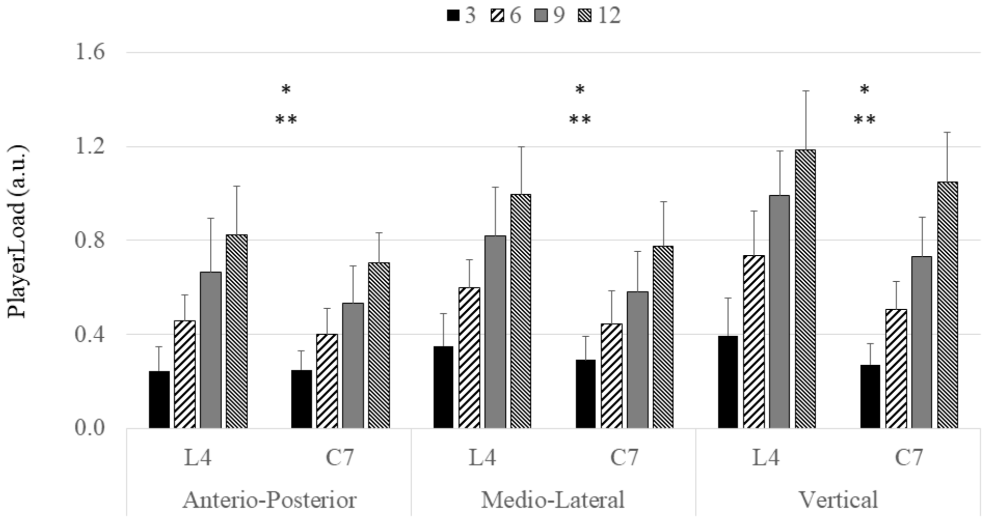

Figure 2. The influence of delivery length and GPS location on planar loading. * denotes significant main effect for delivery strides; ** denotes L4 significantly lower than C7.

Figure 3 summarises the influence of approach length on the relative planar contributions to total PlayerLoad (defined as the sum of the three axial planes) elicited at L4 and C7. The average relative contributions in AP:ML:V was 28:33:39; the average relative contributions were 26:34:40 at L4 and 29:33:38 at C7. There was no significant main effect for number of approach strides in the relative AP ($P = 0.997$; $\eta^2 = 0.001$), ML ($P = 0.135$; $\eta^2 = 0.061$) or V ($P = 0.151$; $\eta^2 = 0.058$) contributions.

There was no main effect for GPS location in relative ML loading ($P = 0.182$; $\eta^2 = 0.020$), and no location *x* strides interaction. There was a significant main effect for GPS location ($P < 0.001$; $\eta^2 = 0.208$) in AP contributions to loading, with greater relative AP loading at C7 than at L4. There was also a significant location *x* strides interaction ($P = 0.049$; $\eta^2 = 0.085$), with the higher AP loading at C7 dissipating as stride length increased. There was also a significant main effect for GPS location ($P = 0.041$; $\eta^2 = 0.047$) in relative V loading, with greater loading at L4. However, the significant location *x* strides interaction ($P = 0.011$; $\eta^2 = 0.118$) highlighted that this greater loading at L4 was only evident from the 3 and 6 stride deliveries, with loading greater at C7 for the 12 strides delivery.

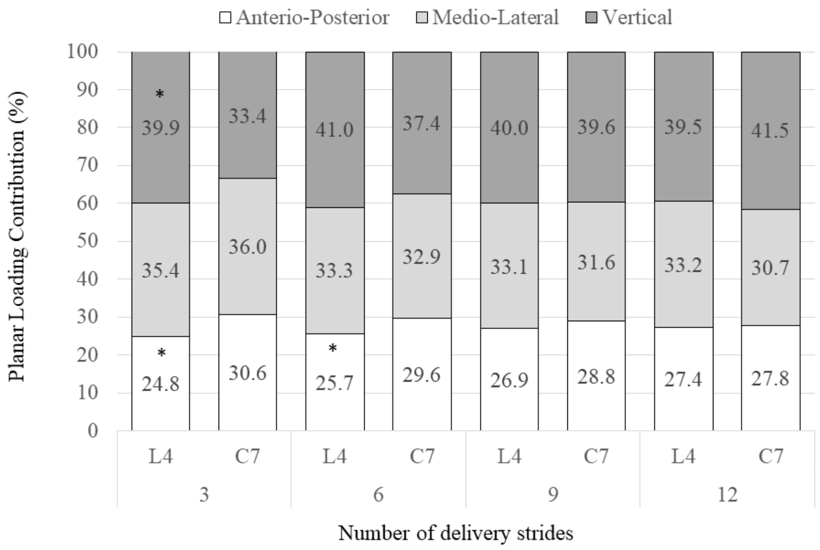

Figure 3. The influence of delivery length and GPS location on the relative planar contributions to total load. * denotes significant difference between L4 and C7.

Discussion

The aim of the current study was to investigate the efficacy of an alternative intervention to current workload restrictions which limit the number of overs bowled. The use of sub-maximal bowling to reduce PlayerLoad at the lumbar spine whilst maintaining performance could have practical applications in the conditioning and rehabilitation of bowlers. Direct comparisons with previous literature are limited and should be treated with caution, given the breadth of metrics used to quantify 'load'. Laboratory-based biomechanical analyses which quantify lumbar segment kinetics [6,10] lack ecological validity, whereas a consideration of workload defined as overs bowled [7,8] has led to restrictions being imposed which may limit the technical development and load tolerance in young bowlers.[11] In the current study an accelerometry-derived metric of loading is used which facilitates an objective measure of bowling whilst retaining a high degree of ecological validity. This approach has been advocated as a means of prescribing and monitoring bowling workload.[13,14]. Any attempts to reduce loading must balance the need to maintain a valid level of performance, either as a workload strategy for young bowlers or in the rehabilitation of bowlers post-injury and establishing return-to-play criteria. Therefore, an intervention that presents a disproportionate reduction in lumbar spine loading relative to the decrease in performance is worthy of consideration, if only as a training and/or rehabilitation tool.

The current study used approach length varying from 3 to 12 strides. The 3 stride approach was significantly slower with respect to ball release speed than either the 9 or 12 stride approaches, most likely as a result of the failure to generate momentum in the delivery that is subsequently transferred to the ball. However, the 6 and 9 stride approaches generated a ball release speed that was not significantly different to the 12 stride approach, but did elicit significantly lower loading. Relative to the 12 stride approach, the sub-maximal 6 stride approach resulted in only a 3.5% decrease in bowling speed at the bowler's crease and a 44% reduction in loading when averaged across all planes and both C7 and L4. The 9 stride approach elicited a 1.5% decrease in performance with a 22% reduction in average loading. This suggests a positive balance between injury risk and performance inhibition. The 3.5% reduction in performance from 6 strides vs. 12 strides (from 87.98 $\mathrm{km \cdot h^{-1}}$ to 85.10 $\mathrm{km \cdot h^{-1}}$) might be too great a sacrifice in elite competition. However, the disproportionately large reduction in loading offers scope for coaches and rehabilitators to manipulate bowling delivery length in training to monitor workload. Similarly, a graded return to play post-injury could objectively increase loading on the bowler, with quantifiable implications on performance and the ability to progress. It is difficult to directly contrast these findings with previous literature, but laboratory-based studies have shown no increase in segmental kinetics over an 8-over bowling spell,[10] whilst injury risk was sensitive to workload and recovery duration.[7,8] Therefore a 22% or 44% reduction in loading from a sub-maximal 9 or 12 stride approach respectively has a substantial practical implication compared with that seen in laboratory studies over 8 overs,[10] and in the increased numbers of overs that could be bowled prior to exceeding a threshold workload.[7,8] This means of reducing total workload might also present an alternative to simply reducing the number of overs bowled as a workload management strategy for young bowlers, or in rehabilitation. Future research should seek to establish an association between PlayerLoad and injury risk, and investigate the efficacy of using this sub-maximal bowling approach as an intervention towards injury prevention.

The 44% reduction in loading from 6 strides (vs 12 strides) is less than the anticipated 50% decrease based purely on stride count. This non-linear translation is a result of the final delivery stride which elicits the greatest loading.[16,17] Since the delivery stride is maintained in all trials, irrespective of the number of preceding strides, there is not a direct conversion in load per stride. It should also be acknowledged that the stride pattern in terms of both stride length and cadence might have been influenced by the altered approach.

When considering the relative contributions of each axial plane to total (summative) load, the average relative contributions in AP:ML:V were 26:34:40 at L4 and 29:33:38 at C7. In the only other study to consider uni-axial contributions to loading, Greig and Nagy reported ratios of 25:36:39 at L4 and 30:28:42 at C7 obtained from full-length deliveries (number of strides not quantified).[11] In the current study the relative AP loading at L4 tended to increase as a function of approach length. This might reflect the greater speed and momentum develop during the run-up, although some previous research has reported an association between lower run-up speeds and ball release speed.[18] ML contributions to loading at L4 were not influenced by approach length, which would have been a concern given the aetiology and mechanism of fast bowling injury.[3-5] With no change in relative ML loading, the lower AP contributions at the shorter delivery lengths were compensated by an increased relative V loading. The greater vertical contributions to loading from the shorter approaches might reflect the attempts to generate ball speed through the upper body as the gains from the transfer of approach speed have been compromised. Salter et al. showed that 80% of within-bowler variation in ball release speed can be attributed to run-up velocity, angular velocity of the bowling arm, and vertical velocity of the non-bowling arm.[19] The angular and planar contributions of the bowling arm and non-bowling arm are likely to have a direct influence on the planar accelerations recorded. Caution should be taken that any technical adaptations (made to compensate for any real or perceived reduction in performance by reducing the length of the approach) made to the bowling action do not increase injury risk. It is also widely acknowledged that different classifications of fast bowlers (e.g. front-on vs. side-on) use different techniques to generate ball speed.[20] The side-on technique is characterised by a shoulder alignment that points down the wicket with an alignment of 180°, whereas the front-on technique has a characteristic shoulder alignment of 240° to the wicket and is susceptible to increased risk of lumbar injury.[6,20]

The current study did not control for bowling action, and future research might consider the loading implications of the front-on vs. side-on techniques given the ecological validity afforded by GPS-based technology. The length of the delivery stride is another research design element that could be afforded greater consideration. Whilst the number of strides constituting a full-length approach varies amongst elite fast bowlers, the implications for sub-maximal bowling in a performance paradigm would benefit from a direct comparison with competition bowling. In the current study all bowlers were injury free, and future research might consider the influence of previous injury on the loading magnitudes and planar contributions during bowling. Non-bowling exercises used in rehabilitation could also be validated against the loading patterns observed during bowling. The ecological validity provided by this approach has considerable potential in both a clinical and performance context. This approach is far more accessible than a laboratory-based analysis of technique, and ball speed can be objective measured in conjunction with loading to inform rehabilitation and return-to-play.

Reduced total load from a sub-maximal approach of 6 or 9 strides, without a comparable decrease in performance, might therefore offer an alternative to reducing the total number of overs bowled when managing workload, for example in young bowlers.[7-9] Similarly, the rehabilitation of a fast bowler might consider that sub-maximal approaches allow for return to competitive levels in terms of performance outcome, without the accumulation of load. This objective and progressive increase in load can be monitored by the practitioner, and used to develop specificity in non-bowling rehabilitative drills. The influence of accelerometer placement on the loading magnitude supports previous observations in fast bowling,[11] with greater absolute values recorded at L4 relative to C7, but also a different planar loading pattern. This has implications for the practitioner, particularly when trying to replicate the specificity of loading elicited during fast bowling. The total PlayerLoad metric does not allow for a consideration of bowling technique complexity, or an appreciation for how loading is accumulated. Greater consideration of planar loading in (p)rehabilitation is warranted to more closely examine the specificity of non-bowling practices used to rehabilitate and condition bowlers. Care should be taken when generalising these findings beyond the population and experimental paradigm used. All bowlers were injury free at the time of testing, and both performance (quantified here as ball speed) and intensity (defined here as PlayerLoad) might be considered using alternate methods. Familiarisation to a reduced approach might induce further technical changes, with implications for loading, and whilst the methodological approach facilitates field-based and ecologically valid analysis of loading, care should be taken when generalising this metric to technique. Care should also be taken when generalising PlayerLoad magnitudes to injury risk.

Conclusions

A sub-maximal approach of 6 strides resulted in a 3.5% reduction in ball speed, but a disproportionately larger 44% reduction in loading. Given the incidence[1-2] and severity[21,22] of spinal injuries in fast bowling, intervention strategies require consideration. Current injury prevention strategies focus on a reduction in workload by reducing total overs bowled for young athletes. Reducing the length of each delivery, rather than the total number of deliveries, might have value in injury prevention for young bowlers. Furthermore, the objective monitoring and gradual progression of loading towards return-to-play has clear implications in rehabilitation. Sub-maximal bowling from reduced delivery lengths might provide a graded and progressive solution to load tolerance during rehabilitation in fast bowlers. The placement of the accelerometer is critical to an interpretation of both the magnitude and pattern of loading, but does provide an ecologically valid, field-based means of monitoring loading during training, competition, and rehabilitation. A consideration of planar (vs. total) loading will also better inform injury prevention programmes and specificity in conditioning drills designed to replicate the demands of bowling.

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