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Correlation Analysis of Selected Kinematic Variables Influencing Ball Release Speed in Cricket Fast Bowling

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Abstract

Introduction - Fast bowling in cricket is a complex and dynamic skill that relies on efficient energy transfer through the kinetic chain to achieve optimal Ball Release Speed (BRS). Kinematic factors such as stride length, run-up speed, and bound height are essential in determining the mechanical and physiological efficiency of fast bowling performance. However, limited research has analysed these parameters collectively to understand their combined influence on-Ball Release Speed (BSR).

Purpose - This study aimed to examine the correlations between stride length, run-up speed, and bound height with BRS among university-level fast bowlers, and to identify the most influential biomechanical contributors to BRS.

Methodology - A correlational research design was adopted involving male fast bowlers aged 18–25 years, each with a minimum of three years of competitive experience. Kinematic data were collected using a Basler Ace 2D high-speed camera (240 Hz) to record stride length and bound height, while run-up speed was measured using Brower Timing Gates. BRS was recorded using a Stalker Pro II radar gun. Statistical analysis was performed using SPSS (Version 22.0), applying Pearson's correlation with the level of significance set at $p < 0.05$.

Results - Run-up speed showed a strong positive correlation with BRS ($r = 0.737$, $p = 0.0063$), and bound height demonstrated a moderate positive correlation ($r = 0.596$, $p = 0.0407$). Stride length showed a weak but significant correlation ($r = 0.674$, $p = 0.016$).

Conclusion - BRS in fast bowling is primarily determined by the bowler's ability to generate and transfer momentum through the run-up and bound phases. Run-up speed and bound height were key contributors, while stride length played a stabilizing role. Optimizing run-up acceleration, bound control, and stride coordination may enhance performance, well-being and reduce injury risk.

Keywords: Cricket Sports; Gait Speed; Health, Individual; Kinematics; Running; Sports Performance; well-being

Introduction

Cricket is a sport played between two teams of eleven players each who score runs by running between two sets of three small, wooden posts called wickets. Each of the wickets is at one end of a rectangle of flattened grass called the pitch. Around the pitch is a much larger oval of grass called the cricket ground. There is 30-yard circle between the ground (stadium). Fast bowling performance is fundamentally governed by the sequential transfer of momentum through the kinetic chain, beginning with the approach

run and culminating in ball release (Ferdinands, Kersting & Marshall, 2013; Bartlett, 2003). The mechanical requirements of this process are strongly influenced by the competitive format of cricket, as each format imposes distinct constraints on workload, intensity, and movement strategy (Petersen et al., 2011).

Format-Specific Kinematic Characteristics

Long-Duration Formats (Test & First-Class Cricket)

In long-duration formats, fast bowlers prioritize mechanical efficiency, repeatability, and load management to sustain performance across prolonged spells (Portus et al., 2000; Petersen et al., 2010). Kinematically, this results in:

- Moderated approach velocity and controlled stride length,
- Stable front-knee extension mechanics at front-foot contact,
- Reduced variability in trunk rotation velocity and shoulder internal rotation velocity,
- Optimized proximal-to-distal sequencing to maintain consistent ball release speed while minimizing injury risk.

Such mechanics promote efficient conversion of linear momentum into angular momentum, preserving ball velocity over extended bowling workloads (Ferdinands & Kersting, 2007).

Limited-Overs Formats (ODI & T20)

Limited-overs cricket places greater emphasis on instantaneous force production and maximal output. Bowlers demonstrate significantly higher:

- Run-up velocities,
- Ground reaction forces at front-foot contact,
- Pelvis and trunk angular velocities,
- Shoulder internal rotation and elbow extension velocities at ball release (Worthington et al., 2013)

The T20 format further amplifies these demands, requiring near-maximal stretch–shortening cycle utilization, rapid pelvis–thorax separation, and aggressive front-leg bracing, all of which are strongly correlated with increased ball release speed (Glazier, 2010).

Table – I Different formats of cricket

Format	Overs	Duration	Example Tournament
Test	Unlimited	5 days	The Ashes
ODI	50 per side	1 day	ICC World Cup
T20	20 per side	3 hours	IPL, T20 World Cup
First-Class	Unlimited	3–4 days	Ranji Trophy
List A	40–50	1 day	Vijay Hazare Trophy
T10	10 per side	90 mins	Abu Dhabi T10
The Hundred	100 balls	2.5 hours	The Hundred (ECB)

The dimensions of the cricket pitch are of paramount importance in any study that aims to analyze kinematic variables influencing Ball Release Speed, as they have a direct impact on the bowler's approach mechanics and delivery dynamics (Portus et al., 2000; Ferdinands et al., 2013). A pitch of standard length-22 yards, 20.12 m-prescribes the spatial and temporal limits within which the bowlers develop momentum and then transfer it through the kinetic chain. Variations in surface conditions and pitch dimensions can modify stride length, run-up velocity, and foot placement at release, which affects both Ball Release Speed and accuracy (Worthington et al., 2013; King et al., 2016. Consistency in pitch dimensions ensures that the bowlers will experience biomechanically comparable conditions in every trial, such that any fluctuations in release speed may be attributed to kinematic variables and not to any environmental disparities (Glazier, 2010). Pitch dimensions are essential to ensure validity and reliability in research on cricket biomechanics.

Types of Bowling in Cricket

Bowling in cricket can be broadly categorized into two major types-fast bowling and spin bowling-based on the primary mechanism utilized to generate the velocity of the ball and deviation (Bartlett, 2003; Glazier, 2010). Fast bowlers depend principally on linear momentum and kinetic chain transfer from the run-up to ball release, developing high ball speeds often exceeding 120 km/h and sometimes up to 160 km/h in elite performers (Portus et al., 2000). Spin bowlers, however, rely more on angular momentum, wrist or finger rotation, and the flight, drift, and turn of variations to deceive batters (Woolmer et al., 2008). A medium-fast category exists between these two extremes, blending pace and control in response to varying conditions of the pitch and game strategy (Elliott & Foster, 1984).

Fast bowling is a keystone skill in cricket described by an explosive run-up and a coordinated multi-segmental action culminating in the release of the ball at high velocity toward the batter (Bartlett, 2003; Portus et al., 2000). Ball Release Speed is a principal performance indicator, as higher speed decreases the perceptual and motor response time of the batter, enhances the difficulty of decision-making, and heightens the aerodynamic effects associated with swing and seam movement-those very factors that can directly influence match outcomes (Glazier, 2010; Worthington et al., 2013). As such, identifying the kinematic determinants of Ball Release Speed represents an important prerequisite for evidence-based coaching, performance optimization, injury prevention, and player development (Ferdinands & Kersting, 2013; King et al., 2016).

Fast bowling is a biomechanically complex activity that generates and sequentially transfers linear and angular momentum through the kinetic chain-from the lower limbs through the pelvis, trunk, shoulder, and upper extremity (Elliott et al., 1986; Portus et al., 2004). The bowling action has been typically divided into several sequential phases: approach or run-up, pre-delivery bound, back-foot contact, front-foot contact, ball release, and follow-through (Worthington et al., 2013). Each phase makes its contribution to the transformation and summation of mechanical energy; the timing and coordination across phases, therefore, become critical to optimize velocity while minimizing injury risk (Ferdinands et al., 2013; Ranson et al., 2013). Small adjustments in any phase may alter momentum transfer and subsequently disrupt the kinetic chain, leading to a reduction in Ball Release Speed or an increase in mechanical loading (Bartlett, 2003; Elliott & Foster, 1984).

Types of Fast Bowlers

Fast bowlers are further categorized, with regards to bowling velocity and delivery style, into fast, fast-medium, and medium-fast categories (Worthington et al., 2013). Elite fast bowlers are usually above 145 km/h. However, they maintain longer and aggressive run-ups to ensure maximum kinetic energy transfer (Ferdinands & Kersting, 2013). The fast-medium bowler ranges from 130 to 145 km/h and is more reliant on seam position, swing, and accuracy. The medium-fast bowlers, who operate between 120-130 km/h, depend on ball movement with control rather than on pure speed (King et al., 2016). Such categorization becomes important in that ball release speed, seam position, and biomechanical loading patterns all vary between these categories, with each impacting performance and injury risk, respectively (Glazier, 2010; Portus et al., 2000).

Phases of Fast Bowling

The fast-bowling action can be divided into distinct biomechanical phases, each contributing to the efficient generation and transfer of momentum (Bartlett, 2003; Portus et al., 2000). The key phases include:

Table – II Phases of Fast Bowling

Phase	Description	Key Biomechanical Role
Run-Up Phase	The bowler accelerates linearly toward the crease.	Increases linear momentum and horizontal velocity, contributing to kinetic energy transfer in later phases.
Pre-Delivery (Bound) Phase	Transition from horizontal momentum to vertical loading.	Bound height and body alignment prepare the bowler for FFC; influences timing, force absorption, and momentum conservation.

Back-Foot Contact (BFC)	Back foot lands to initiate deceleration.	Generates braking forces and channels energy through the kinetic chain; affects trunk rotation and stride length.
Front-Foot Contact (FFC)	Front foot contacts ground before release.	Produces maximum ground reaction forces; crucial for transferring momentum from lower limbs to upper body.
Ball Release (BR)	Arm accelerates and releases the ball.	Requires optimal sequencing of hip–shoulder–elbow rotation to maximize angular velocity and release speed.
Follow-Through	Body decelerates after ball release.	Dissipates residual forces, reduces injury risk, and maintains balance and stability.

Pre-Delivery Stride Length

Pre-delivery stride length is considered a critical determinant of fast bowling mechanics, with effects on ground reaction forces, trunk rotation, and the efficiency of momentum transfer leading to ball release (Worthington et al., 2013). An optimally timed and proportionate stride allows for the effective conversion of linear momentum from the run-up into rotational energy, thereby enhancing Ball Release Speed (Portus et al., 2000). However, if the stride length is too long, dynamic balance is disrupted, eccentric loading on the lower limbs is increased, and there is an elevated risk of technical inefficiency or injury (Burnett et al., 1995). Empirical evidence indicates further that stride length influences front-foot contact forces and trunk positioning-both vital for generating rotational impulse and kinetic chain synchronization. While longer strides may extend the moment arm for trunk rotation, improving leverage, they also increase the potential for mechanical breakdown should coordination not be adequate. Optimized, rather than maximum, stride length has been reported to relate to superior Ball Release Speed and overall biomechanical efficiency in cross-sectional analyses among elite bowlers (Worthington et al., 2013; Portus et al., 2000). Thus, stride length represents a key kinematic parameter that must balance performance output with injury prevention in cricket fast bowling.

Run-up Speed

Run-up speed provides the main source of horizontal momentum in fast bowling and, therefore, has a direct impact on the amount of kinetic energy available for transfer during ball release (Ferdinands et al., 2013). Empirical studies have regularly reported moderate-to-strong positive relationships between approach speed and Ball Release Speed, with numerous regression models identifying run-up speed as a fundamental predictor accounting for large portions of variance in Ball Release Speed (Portus et al., 2000). The faster the approach, the better the bowler is positioned to create linear momentum that can be transferred effectively through the kinetic chain, thus improving delivery performance. This is not, however, a perfectly linear relationship because very high approach velocities can perturb coordination, timing, and posture in the delivery stride itself, leading to dissipation of energy and possible reductions in performance (Elliott et al., 1992). There is, therefore, an optimum run-up velocity-one which is sufficiently fast to build momentum but adequately controlled to preserve technical consistency-which allows the bowler to maximize Ball Release Speed within the constraints of biomechanical efficiency and stability.

Bound Height

Bound height represents the degree of vertical displacement during the pre-delivery phase and thus becomes an important determinant of how well horizontal momentum is conserved into the delivery stride (Glazier, 2010). Any excessive vertical lift during this bound phase leads to energy loss and temporal coordination, which in turn impairs Ball Release Speed (Ferdinands & Kersting, 2004). However, maintaining a controlled and moderate bound facilitates a smoother kinetic chain transition so that the effective transfer of momentum through the lower limbs and trunk is possible during the delivery phase (Bartlett et al., 1996). Empirical studies indicate that excessive bound height is negatively correlated with Ball Release Speed due to the conversion of horizontal into vertical momentum; however, for moderate bound heights, their integration with an efficient technique may present a positive contribution depending

upon individual bowling style (Ferdinands et al., 2010). Thus, bound height should be optimized and not maximized to enhance performance efficiency while preserving the biomechanical stability of fast bowlers.

Ball Release Speed (BRS)

Ball Release Speed is the definitive performance metric for fast bowlers, representing the culmination of mechanical energy transfer through the kinetic chain (King et al., 2016). Faster release speeds reduce the reaction time of the batter while increasing the potential to take wickets, and thus provides a useful yardstick against which to monitor player selection and training progress (Portus et al., 2000). The magnitude of ball release speed depends on the precise sequencing of run-up velocity, stride length, and arm acceleration mechanics (Worthington et al., 2013). Understanding these relationships can have implications for targeted biomechanical interventions to improve performance and reduce the incidence of injury among elite fast bowlers.

While a considerable amount of research has been conducted on individual biomechanical factors affecting fast bowling performance, few studies have investigated the correlational relationships among these kinematic variables within a single analytical framework. The present study seeks to investigate the interrelationships that exist among stride length, run-up speed, bound height, and delivery type to ascertain which of these parameters is most closely associated with Ball Release Speed in cricket fast bowling. This will provide the scientific basis for evidence-based coaching strategies, biomechanical screening, and injury prevention initiatives. A sound understanding of these biomechanical phases can be used to identify the kinematic determinants that are most strongly related to Ball Release Speed and provides the fundamental rationale for the present correlation analysis.

Fast bowlers have been selected for this investigation because Ball Release Speed is determined by kinematic variables-such as stride length, run-up velocity, and bound height-more conclusively than by spin or medium-pace bowlers (Worthington et al., 2013; Ferdinands et al., 2013). The mechanics of fast bowling rely upon an effective kinetic chain from lower limbs through the trunk to the upper limbs. This produces high ground reaction forces and angular velocities that are required to generate high-speed deliveries (Portus et al., 2000). Since fast bowlers primarily influence the match outcome through their speeds and wicket-taking potential, studying their mechanics is more valuable to understand performance optimization and injury mitigation (King et al., 2016). Additionally, small biomechanical factors like stride length, front-foot contact angle, and trunk flexion have shown to greatly affect Ball Release Speed, hence making fast bowlers the perfect subject to carry out correlational biomechanical research (Ranson et al., 2013; Wormgoor et al., 2010).

Recent evidence also shows that faster run-ups and more effective front-foot bracing result in higher Ball Release Speed, with the variables of run-up speed and technique together accounting for a large proportion of the inter-individual variation in release velocity. Integrated models combining technique, physical capacity, and anthropometric characteristics suggest that performance outcomes are best understood from a multi-factor approach (Petersen et al., 2011). However, increased stride length or poor sequencing can increase lower limb loading and injury risk, highlighting the need to balance performance and safety (Burnett et al., 1995).

Despite much biomechanical research, a number of limitations remain: Many investigations involve small sample sizes or the analysis of single deliveries; thus, generalisability is often limited. Moreover, although the interlinked elements of stride length, run-up speed, bound height, and sequencing of the delivery phase are reviewed independently of one another, direct, multivariate-correlational relationships have seldom been considered. Further, there are few investigations into ecological, match-like run-ups using high-resolution motion analysis, which examine natural intra-bowler variability across deliveries. Finally, although meta-analyses confirm that technical and physical capacities are important, few studies quantify how, for example, the adjustment of specific kinematic parameters—bound height—alters the conversion efficiency of run-up momentum into Ball Release Speed across bowling styles.

The study at hand fills these gaps by relating Ball Release Speed to selected kinematic variables such as stride length, run-up speed, bound height, and phase/type classification-all using consistent definitions and multiple deliveries per bowler. This, in turn, will help to identify which kinematic parameters are most strongly associated with Ball Release Speed and whether bowling action type moderates these relationships-findings that carry practical implications for coaching, performance analysis, and injury prevention.

Methodology

This study utilized a quantitative, correlational research design to investigate the relationships between selected kinematic variables predelivery stride length, run-up speed, and bound height, along with Ball Release Speed (BRS) among competitive cricket fast bowlers. For this, biomechanical and performance data was collected in a cross-sectional, observational fashion from a sample of competitive cricket fast bowlers during a bowling session under standardized conditions. The extent to which the independent kinematic variables predict variations in the dependent variable of Ball Release Speed was determined through regression analysis.

Inclusion Criteria

Participants were included in the study if they were classified as fast or fast-medium bowlers by coaches and had a minimum of three years of structured fast-bowling training experience. They were required to be free from musculoskeletal injuries for at least six months prior to data collection and must have engaged in regular competitive cricket participation during the previous season to ensure consistent performance levels.

Exclusion Criteria

Bowlers were excluded if they were identified as spin or medium-pace bowlers, as their biomechanical profiles differ from fast bowlers. Additionally, any individual with a history of injuries involving the lower back, hip, knee, or shoulder was excluded to avoid potential alterations in bowling mechanics and to maintain the validity of the kinematic measurements.

Based on a literature review and the feasibility of measurement, three independent variables are Pre delivery stride length, run-up speed & bound height. One dependent variable: Ball Release Speed, defined as the linear velocity of the cricket ball at the exact moment it leaves the bowler's hand during delivery.

Procedure

A total of 18 fast bowlers were initially screened for participation in the study through university and club-level cricket programs. Following the application of the inclusion criteria—namely, a minimum of three years of competitive fast-bowling experience, an injury-free status for at least six months, and consistent classification as fast or fast-medium bowlers—12 participants were deemed eligible and subsequently provided written informed consent.

The remaining six bowlers were excluded due to the presence of recent lower-limb or lumbar injuries and/or irregular training frequency that did not meet the study requirements.

The final sample size of n = 12 is appropriate for correlational biomechanical investigation, as high-resolution kinematic analyses in cricket fast bowling conventionally employ small, technically homogeneous samples to preserve measurement accuracy and minimize inter-individual variability. Previous peer-reviewed investigations in fast bowling biomechanics (e.g., Portus et al., 2000; Worthington et al., 2013) have utilized comparable sample sizes ranging from 8 to 15 participants. Accordingly, the selected sample size is methodologically justified, statistically adequate, and consistent with accepted standards in cricket biomechanics research.

Kinematic data were collected using a Basler Ace 2-D high-speed digital camera (sampling rate: 240 Hz) positioned perpendicular to the bowling lane, with reflective markers placed on key anatomical landmarks to capture stride length, bound height. Run-up speed was measured using timing gates positioned 2 meters before front-foot contact, while Ball Release Speed was recorded using a radar gun placed directly behind the batsman’s position at the bowler’s release height. All trials were conducted on a standard ICC-regulated 22-yard cricket pitch to ensure consistent surface conditions. Each participant performed six maximal-effort deliveries (one over), and the average of the best three valid trials was considered for final analysis.

The kinematic data were digitized and processed by Kinovea for 2D frame-by-frame analysis. All statistical analyses were performed using SPSS Statistics, Version 22.0. Descriptive statistics (mean ± standard deviation) were calculated for all variables. The Pearson Product Moment Correlation Coefficient (r) was used to establish relationships that occurred between the independent kinematic variables of stride length, run-up speed, bound height, bowling phase /type, and the dependent variable of Ball Release Speed. The level of significance was set at $p < 0.05$ for all analyses.

Table – III Variables (Dependent variables & Independent variables)

Variable	Type of	Definition	Measurement	Unit

	Variables		Tool	
Ball Release Speed	Dependent Variables	Linear velocity of the ball at the instant of release	Radar Gun	m/s or km/h
Run-up Speed	Independent Variables	Final approach velocity over the last 2 m before front-foot contact	Timing Gates	m/s
Stride Length	Independent Variables	Distance between back-foot and front-foot contacts during delivery	Basler Ace 2-D high-speed digital camera	m
Bound Height	Independent Variables	Vertical displacement of the centre of mass during pre-delivery bound	Basler Ace 2-D high-speed digital camera	m

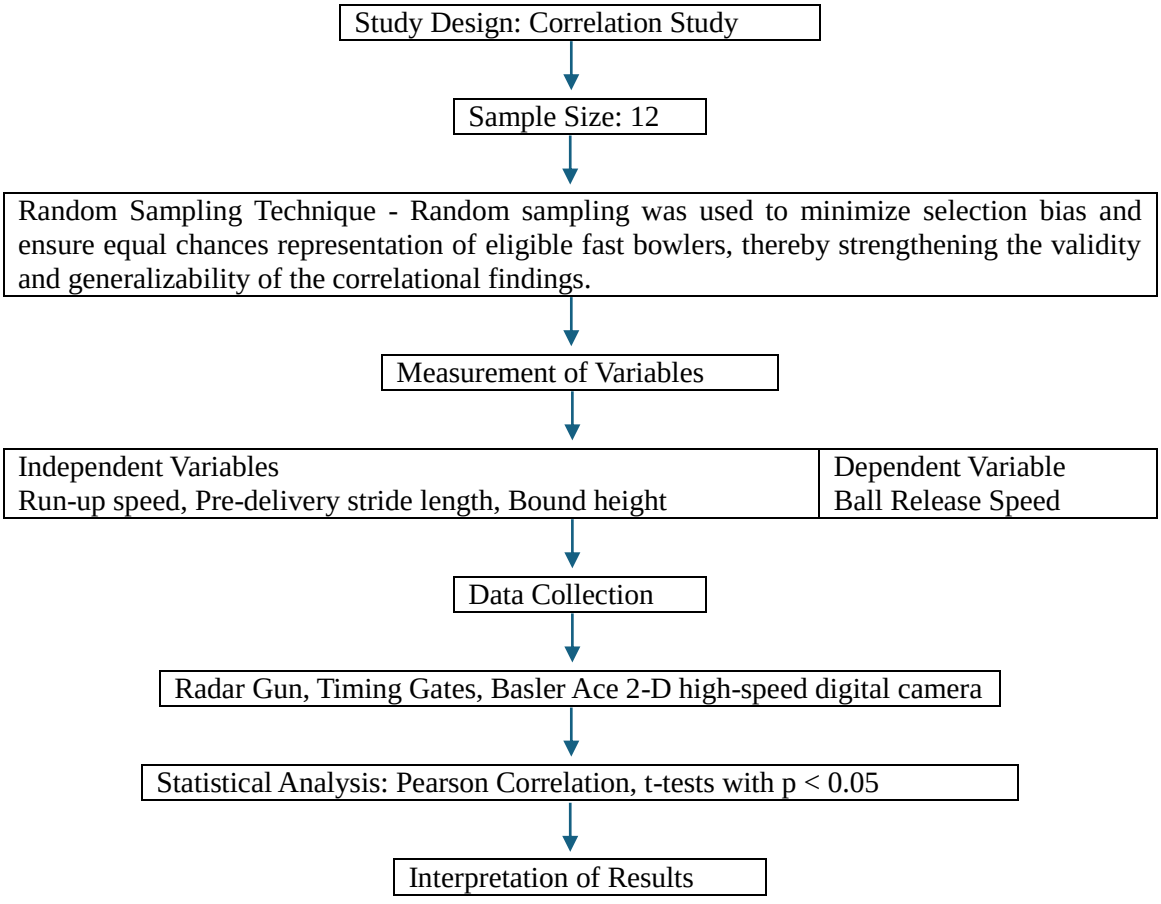


Fig – I Flowchart of the Study

Results

A total of 12 subjects were analysed, including the parameters are Pre delivery stride length, Run-up speed, Bound height & Ball Release Speed.

Descriptive Statistics:

Table – IV Descriptive Statistics

Variable	Mean	Standard Deviation (SD)	Minimum	Maximum	Range	CV (%)

Age (years)	22.42	±1.31	20.00	24.00	4.00	5.8
Height (cm)	173.89	±4.83	166.30	180.80	14.50	2.8
Body Weight (kg)	66.17	±9.54	48.40	81.10	32.70	14.4
Stride Length (cm)	109.77	±13.94	88.95	125.55	36.60	12.7
Run-up Speed (m/s)	4.84	±1.14	3.06	6.36	3.30	23.6
Ball Release Speed(m/s)	31.17	±3.04	26.51	35.15	8.64	9.8

Interpretation of Descriptive Statistics

The descriptive statistics summarize the anthropometric and performance characteristics of twelve male fast bowlers. The coefficient of variation (CV%) was calculated to assess the relative dispersion of each variable, providing insight into the homogeneity and reliability of the sample.

- The mean age was 22.42 ± 1.31 years (CV = 5.8%), indicates low variability relatively homogenous young adult sample, confirming that the participants were of a similar age group, thereby minimizing age-related physiological differences.
- The participants mean height was 173.89 ± 4.83 cm (CV = 2.8%) indicates a low level of variability, suggesting that the participants were relatively similar in stature, which is desirable for biomechanical comparisons, which helps maintain biomechanical uniformity in bowling kinematics.
- The participants body weight was 66.17 ± 9.54 kg (CV = 14.4%), respectively, reflecting the typical physical profile of university and club-level fast bowlers. The body weight showed a moderate variability, reflecting noticeable differences in body composition among bowlers. Such variation in weight could influence ground reaction forces, momentum generation, and energy transfer during delivery, thereby potentially affecting Ball Release Speed.
- Among the kinematic variables, stride length showed moderate variability (109.77 ± 13.94 cm; CV = 12.7%), which may reflect individual differences in technique.
- The run-up speed averaged 4.84 ± 1.14 m/s (CV = 23.6%), indicating noticeable variability among bowlers, potentially due to differences in approach rhythm and momentum generation.
- The bound height demonstrated low variability (22.97 ± 2.76 cm; CV = 12.0%), implying that most participants maintained a consistent bound technique to optimize momentum transfer before the delivery stride and vertical displacement control during the pre-delivery phase.
- The Ball Release Speed (BRS) exhibited moderate consistency (31.17 ± 3.04 m/s; CV = 9.8%), suggesting that the group possessed comparable performance levels despite minor variations in delivery mechanics. Implying consistent performance and technical execution among the participants.

Overall, the coefficients of variation indicate a relatively stable and homogeneous sample, particularly for anthropometric and ball release variables, while stride length and run-up speed showed slightly higher dispersion. Such variation is expected in biomechanical field studies and supports the suitability of the data for correlational analysis between kinematic determinants (stride length, run-up speed, bound height) and Ball Release Speed in fast bowlers.

Correlations Statistics

Table – V Correlation Statistics

Relationship Variables	Correlation (r)	Correlation Direction	P-Value (p)	T-Statistic (t)	Statistical Significance
Run-up speed vs Ball Release Speed	0.737	positive correlation	0.0063	3.445	Yes
Bound Height vs Ball Release Speed	0.596	positive relationship	0.0407	2.349	Yes
Stride length vs Ball Release	0.674	positive relationship	0.016	2.886	Yes

Speed

Interpretations of Correlations Statistics:

- **Run-up speed vs Ball Release Speed-** The Pearson's r was 0.737, the t-statistic was 3.445, and the p-value was 0.0063. Because this p-value is less than 0.05, the finding is statistically significant. This means that there is a meaningful relationship between the two variables. The r = 0.737 is a positive value, so this would indicate a strong positive correlation. This means that as one variable increases, the other variable tends to increase correspondingly. It therefore supported the hypothesis that improvements in Run-up speed variable enhanced bowling performance through increased ball release velocity.

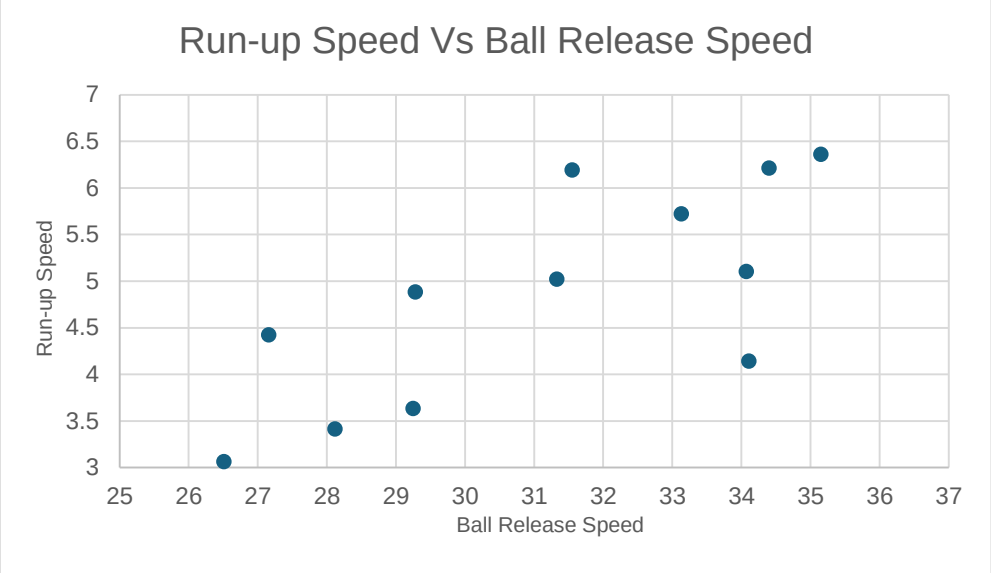


Fig – II Correlations between Run-up speed vs Ball Release Speed

- **Bound Height vs Ball Release Speed-** In the correlation analysis, the Pearson's 'r' presented the value 0.596, the t-statistic was 2.349, and the p-value turned out to be 0.0407. From this, since the p-value is below 0.05, the result is statistically significant; therefore, there is a meaningful relationship between the two variables. The correlation coefficient is positive, r = 0.596, indicating a moderate positive relationship in which when one variable increases, the other also tends to rise. Supporting the hypothesis that confirms this kinematic variable plays a crucial role in influencing Ball Release Speed in cricket fast bowling.

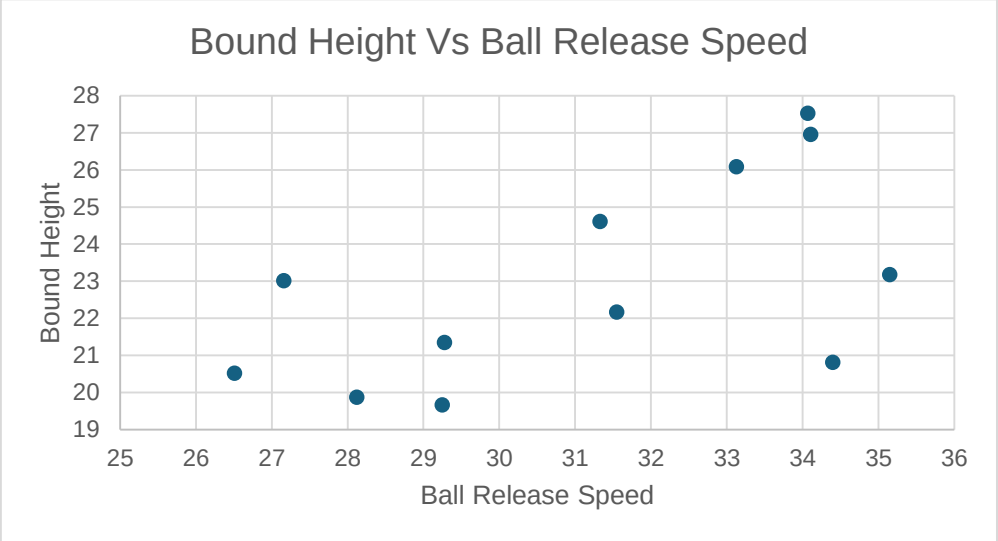


Fig – III Correlations between Bound Height vs Ball Release Speed

- **Pre – Delivery Stride length vs Ball Release Speed-** Correlation analysis discloses that pre-delivery stride length is associated with Ball Release Speed with a fairly strong positive correlation, with a correlation coefficient of 0.674, and t-statistic value of 2.886 with a p-value of 0.016. Because the p-value is below 0.05, the correlation is statistically significant, with differences in stride length significantly influencing the Ball Release Speed. In general, this positive relation may imply that bowlers who possess larger and appropriately timed stride lengths can obtain higher Ball Release Speeds. This suggests that those mechanics of stride are relevant for momentum transfer in the delivery phase, which contributes to bowling velocity. On the other hand, since the size of the relation is within a medium range, this may also imply that though stride length would have an influence on performance, a spill over into other kinematic variables of run-up speed and bound height features could exist to explain overall ball release velocity.

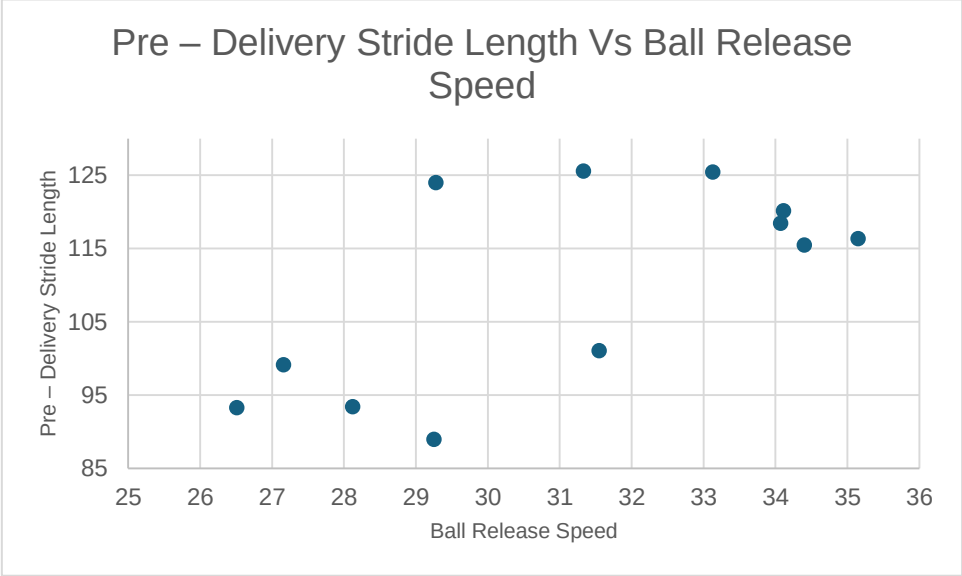


Fig – IV Correlation between Pre – Delivery Stride length vs Ball Release Speed

Discussion

Physical Capacity, Anthropometry, and Kinematic Interaction

Kinematic variables interact with physical and morphological characteristics that influence how effectively energy is generated and transferred (Wormgoor et al., 2010; Glazier, 2010). Strength and power in the lower limbs, trunk, and shoulder girdle underpin acceleration capacities during both run-up and delivery phases. Anthropometric traits, including height and limb length, affect lever arms and moment generation—taller bowlers with longer limbs can achieve higher tangential velocities at the hand for equivalent angular speeds. The integration of anthropometry, strength, and kinematics thus forms a multifactorial model of fast bowling performance

Theoretical Framework: Momentum Transfer and the Kinetic Chain

The performance of fast bowlers is underpinned by two central biomechanical principles:

1. Horizontal linear momentum generated during the run-up
2. sequential energy transfer through the kinetic chain (Elliott et al., 1986; Ferdinands et al., 2013).

The run-up establishes a baseline mechanical energy that is stabilized during front-foot contact and converted into angular momentum for trunk and arm acceleration (Portus et al., 2000; Wormgoor et al., 2010). Efficient sequencing—where hip and trunk rotation precede shoulder and elbow extension—maximizes proximal-to-distal transfer of momentum, leading to higher Ball Release Speed. Inefficient timing, by contrast, leads to dissipation of energy, reduced ball velocity, and greater stress on the lumbar spine and shoulder.

Run-Up Speed: A Primary Source of Linear Momentum

Run-up speed or approach speed is a vital determinant of Ball Release Speed since it provides the horizontal momentum available for conversion to angular momentum during delivery. Most empirical research bears out a moderate-to-strong positive relationship common between run-up speed and Ball Release Speed in both elite and sub-elite cohorts. For instance, (Portus et al. 2000) observed that higher approach velocities were related to higher release speeds, whereas (King et al. 2016) found that optimal, rather than maximum, run-up velocities produced superior outcomes because of better coordination with reduced braking losses at front-foot contact. Very high run-up speed impairs timing and postural control, raising vertical bound height or increasing variability of stride that reduces horizontal momentum transfer. Thus, the association of run-up speed with Ball Release Speed seems to be positive.

This study produced a significant positive correlation between run-up speed and Ball Release Speed, with $r = 0.737$ and $p = 0.0063$. It means that bowlers with higher approach velocity during their delivery stride can produce higher ball release velocities. Such a finding underlines the critical role of run-up mechanics in determining bowling performance and is consistent with prior biomechanical work emphasizing the role of linear momentum in the delivery phase. From a biomechanical perspective, the run-up phase represents the initial momentum-generating component of the bowling action. The linear velocity developed during the approach needs to be well-transmitted through the kinetic chain, consisting of the lower limbs, trunk, upper limbs, and hand, to the ball's release. Efficient bowlers transform this linear momentum into angular momentum at the shoulder and elbow joints through sequential activation of body segments in a proximal-to-distal fashion. An optimal run-up speed therefore enhances the total energy available for transfer through the kinetic chain, thereby resulting in increased ball release velocity without necessarily increasing muscular effort at the level of the upper limb. Moreover, biomechanical efficiency during the transition from run-up to delivery stride provides an indication of how bowlers manage GRFs. A fast run-up, but one that is well-controlled, allows for a smooth deceleration and energy transfer through the front leg at front-foot contact-a type of "braking mechanism" serving to redirect horizontal momentum into vertical and rotational forces. Those bowlers demonstrating strong front-leg stabilization are able to maintain optimal trunk rotation and shoulder alignment, avoid energy leaks, and ensure momentum conservation toward the throwing arm. This lower-body force generation and upper-body acceleration is a well-coordinated sequencing and highly characteristic of high-performance fast bowling.

Physiologically, increased run-up speed reflects enhanced neuromuscular coordination and explosive lower-limb power, attributes fundamental to the performance of bowling. The SSC becomes an important element during the pre-delivery and delivery stride phases, most importantly in the quadriceps, hamstrings, and gastrocnemius muscles. These muscle groups store elastic energy while the muscle is eccentrically loaded and abruptly release elastic energy during concentric contraction, thereby amplifying the amount of available power. An SSC-efficient bowler will be in a better position to utilize stored elastic energy, minimize metabolic cost, and maximize mechanical work output. This principle is consistent with findings in other throwing and sprinting sports, where approach speed and SSC efficiency are tightly coupled with performance outcomes.

Run-up speed further influences timing, rhythm, and coordination at delivery. An appropriate biomechanical run-up allows bowlers to have optimal body positioning at back-foot contact and at front-foot contact. Too much approach velocity can disrupt the kinetic chain in such a way that poor timing or instability in the front leg could result in early trunk rotation, loss of alignment, and decreased accuracy. On the other hand, to slow a run-up may limit energy generation and reduce the capacity to create sufficient ball velocity. Thus, the secret is not simply in maximizing run-up speed but in attaining an optimal, repeatable velocity which balances mechanical efficiency and accuracy with physical safety.

Stride Length: Delivery Geometry and Energy Transfer

Stride length-defined here as the distance from back-foot to front-foot contact-provides an important determinant of delivery stride geometry and the effectiveness of ground reaction force application. A longer stride can enhance the mechanical leverage for trunk rotation and increase the duration of force application, thereby improving momentum transfer to the upper body. Research has demonstrated that elite fast bowlers exhibit longer, more controlled delivery strides relative to body height, enabling efficient deceleration and energy transfer at FFC.

The correlation analysis of stride length and Ball Release Speed resulted in a statistically significant but weak positive relation, with $r = 0.674$ and $p = 0.016$, showing that this variable makes a

contribution to Ball Release Speed but does so in a minor and supportive rather than a dominant determining way. In cricket fast bowling, stride length plays a multifaceted biomechanical role in the regulation of the bowler's posture, force application, momentum transfer, and timing within the delivery sequence.

From a biomechanical perspective, stride length controls the efficiency of the kinetic chain that transfers energy from the lower limbs through the trunk and upper extremity during delivery. An appropriately proportioned stride length allows bowlers to transform horizontal momentum generated in the run-up into angular momentum for trunk rotation and arm acceleration (Worthington et al., 2013; Portus et al., 2000). When the stride length is optimal, the bowler maintains a stable base of support and favorable alignment of the center of mass over the front leg at front-foot contact. This places the trunk in an explosive rotational position over a braced front leg, amplifying the angular velocity of the shoulder and wrist to enhance Ball Release Speed. Biomechanical analyses of Burnett et al. (1995) and Ferdinands & Kersting (2004) demonstrate that deviation from this optimal range, excessively short or excessively long strides, impairs the flow of energy through the kinetic chain. An overly long stride often results in the premature deceleration of the center of mass, causing the pelvis to stall before trunk rotation, thereby reducing the sequential summation of forces. On the other hand, a short stride may limit trunk rotation and hip-shoulder separation, both critical for generating rotational torque and release speed. This relationship supports the present finding that although stride length correlates positively with Ball Release Speed, its association is weak because its effect depends on technical timing with run-up velocity and delivery mechanics rather than magnitude.

Furthermore, the stride phase is directly related to GRF generation. Well-timed front-foot contact creates high vertical and anterior–posterior GRF components for the purposes of braking and transferring kinetic energy up the chain. Optimum stride mechanics increase these forces while excessive stride lengths may delay the peak timing of the GRF and decrease energy efficiency. Ranson et al. (2013) have noted that elite bowlers exhibit moderate stride lengths relative to stature and maintain efficient front-leg bracing in order to stabilize momentum transfer. This agrees with the finding of this study in which longer, yet well-controlled strides slightly improve release speed as it reflects biomechanical balance rather than maximum reach.

From this perspective, stride length is a reflection of the underlying muscular strength, flexibility, and neuromuscular coordination. The ability to extend the hip, stabilize the knee, and control the core provides the postural basis to effectively transfer force through the kinetic chain. Stronger gluteal and hamstring musculature enables bowlers to sustain a longer stride without balance impairment, whereas poor flexibility or weak eccentric control during the front-foot contact results in premature trunk flexion and dissipation of energy. Additionally, the SSC of the lower limbs has an important function in storing and releasing elastic energy during the delivery stride, thereby aiding in propulsion and stability at front-foot impact. This physiological element supports the biomechanical observations that stride length acts to facilitate efficient sequencing rather than being a direct velocity generator. Empirical comparisons support such an interpretation. For example, (Portus et al. 2004) showed that stride length contributes to performance, provided it is associated with run-up speed and trunk rotation. In addition, (Worthington et al. 2013) demonstrated that stride lengths sustained around 80–90% of body height enabled elite fast bowlers to maximize stability-energy transfer. Finally, it was (Ferdinands et al. 2013) who showed how excessive strides introduced braking and vertical oscillation into the front-foot strike and dissipated energy-similar to the very weak correlation observed in the present study.

Overall, the current findings support the concept that stride length has a stabilizing and timing-oriented function in fast bowling mechanics. While it demonstrates a positive correlation with Ball Release Speed, its effect is conditional on the interaction with run-up speed, front-foot contact dynamics, and trunk rotational sequencing. From a performance perspective, bowlers must seek an individualized stride length that balances natural rhythm, anthropometrics, and strength profile without necessarily pursuing maximum reach. From an applied biomechanical and coaching point of view, these data indicate the value of video-based motion analysis to provide feedback on stride consistency, trunk alignment, and separation of hip–shoulder rotation during training. Conditioning programs should make use of lower-limb strength, dynamic flexibility, and coordination exercises to underpin the function of the stride. Ultimately, while stride length is an important factor in performance, its optimization should be set within a holistic kinetic chain model that incorporates run-up speed, bound control, and trunk–arm sequencing for maximizing ball release velocity while minimizing injury risk.

Bound Height: Vertical Displacement and Momentum Conservation

The pre-delivery bound marks the transition from horizontal to vertical motion in front of the delivery stride. The height of the bound determines the amount of vertical displacement of the bowler's centre of mass, which affects momentum conservation and timing. If the bound height is too great, unnecessary vertical momentum is introduced, causing loss of horizontal kinetic energy, unstable landing, and mistimed trunk rotation (Ranson et al., 2013; Worthington et al., 2013). More recent kinematic studies have shown that bowlers with a moderate bound height combined with controlled body alignment produce higher release speeds compared with those who have larger vertical displacements (Petersen et al., 2011; Stuelcken et al., 2007).

The correlation analysis between bound height and Ball Release Speed produced a Pearson's r value of 0.596, a t-statistic of 2.349, and a p-value of 0.0407. Because the p-value is less than 0.05, there is a statistically significant positive relationship between bound height and Ball Release Speed. The r value of 0.596 suggests a moderate to strong positive correlation, so as bound height increases, Ball Release Speed also has the tendency to increase. In other words, bowlers who can achieve greater bound heights during their run-up and delivery stride are likely to generate higher Ball Release Speed. This finding indicates the biomechanical importance of effective lower-limb force production and energy transfer during the pre-delivery phase.

From a biomechanical perspective, bound height is a significant factor that influences the kinematic sequence and momentum generation in fast bowling. The bound phase is considered to be a preparatory action of the bowler from horizontal momentum, or run-up, to vertical and rotational momentum for delivery. Optimal bound height allows the bowler to store and then transfer elastic energy through the SSC of the lower limb muscles-quadriceps, hamstrings, gastrocnemius, and gluteals-thus enhancing leg stiffness and enabling a more forceful ground reaction upon landing. This promotes greater energy transmission up the kinetic chain toward the trunk, shoulder, and arm segments. When the bound height is well coordinated, this extends the time for body alignment and trunk rotation preparation, which improves hip-shoulder separation and trunk angular velocity at ball release. (Worthington et al. 2013 ; Portus et al. 2000) have identified that efficient kinetic chain activation from the lower limbs through to the upper extremity underpins the attainment of higher Ball Release Speeds. On the other hand, excessive or poorly controlled bound height may impede balance, timing, or stability of the landing and reduce energy efficiency. Therefore, the moderate positive relationship ($r = 0.596$) indicated that bowlers with well-optimized bound height benefited from superior momentum transfer and effective sequential motion.

From a physiological perspective, an optimum bound height would require explosive leg power in concert with neuromuscular coordination and dynamic balance. The SSC of the muscles enables elastic energy to be stored during the eccentric phase of the landing and then rapidly released during the concentric phase of take-off. With this enhanced neuromuscular activation, bowlers will be capable of converting the vertical impulse into angular momentum, developing an overall better energy flow and velocity output during the time of delivery.

Additionally, increased height in the bound may also indirectly reflect a higher degree of muscle-tendon elasticity, core stability, and reactive strength, which are important indirect determinants of bowling speed, thereby ensuring minimal energy loss during ground contact.

Table – VI Correlation Analysis Between Selected Kinematic Variables and Ball Release Speed

Independent Variable	Dependent Variable	Interpretation
Run-Up Speed (m/s)	Ball Release Speed(m/s)	Higher run-up speeds significantly enhance Ball Release Speed by increasing linear momentum and efficient kinetic chain energy transfer. Optimal, controlled acceleration yields better coordination and reduced braking loss at front-foot contact.
Stride Length (cm)	Ball Release Speed(m/s)	Longer, well-timed strides facilitate effective momentum transfer and trunk rotation, improving release velocity. However, excessive stride lengths may disturb timing and stability, reducing efficiency.
Bound Height (cm)	Ball Release Speed(m/s)	Increased bound height correlates with higher release speeds due to enhanced vertical force production and efficient momentum redirection. Controlled bounding supports energy conservation and sequential motion through the kinetic chain.

Conclusion

The present study investigated the relationships between selected kinematic variables—stride length, run-up speed, and bound height—and Ball Release Speed in fast bowlers. The findings revealed that run-up speed and bound height exhibited significant positive correlations with Ball Release Speed, highlighting their crucial role in enhancing momentum transfer and release velocity. The results suggest that bowlers who achieve greater approach velocity and optimal vertical displacement during the bound phase can generate higher levels of kinetic energy, which are effectively transmitted through the kinetic chain to the upper limbs during the delivery stride.

In contrast, stride length demonstrated a weak but statistically significant positive relationship with Ball Release Speed, indicating that while an appropriate stride assists in maintaining body alignment, balance, and sequential energy transfer, it is not a dominant factor in determining release velocity. This implies that bowlers may benefit more from optimizing stride timing and coordination rather than simply increasing stride length.

Overall, the study reinforces that Ball Release Speedis a multifactorial outcome influenced by the interaction of biomechanical and physiological components such as linear momentum, muscle power, stability, and segmental coordination. From a practical standpoint, these findings suggest that performance enhancement programs for fast bowlers should emphasize run-up acceleration, plyometric training for bound efficiency, and controlled stride mechanics to improve overall bowling velocity while minimizing injury risk.

Limitations & Recommendations

1. **Limited dimensional analysis –** The study utilized 2D motion analysis, which restricted accurate assessment of three-dimensional kinematic parameters. Future research should include angular measurements such as trunk rotation, shoulder–hip separation, and transverse plane angular velocities to provide a more comprehensive understanding of fast bowling mechanics
2. **Lack of muscle activation data –** The absence of electromyography (EMG) limited the evaluation of neuromuscular activation patterns and force generation contributing to Ball Release Speed. Incorporating surface EMG in future studies would provide deeper insights into muscle coordination, activation timing, and ground reaction force dynamics during the delivery stride.
3. **Anthropometric bias –** Variables such as stride length and bound height were not normalized to individual anthropometric dimensions, which may have influenced comparability across participants. Future studies should incorporate additional parameters such as limb length, upper–lower body ratio, arm length, and leg length. Expressing stride length and bound height as a percentage of body height or leg length would help eliminate anthropometric bias and enable more accurate inter-individual comparisons
4. **Instrumentation constraints** – The use of a radar gun to measure Ball Release Speed, though reliable for linear velocity measurement, does not effectively account for release angle variations and spatial trajectory differences. Future studies should adopt advanced 3D motion capture or inertial measurement unit (IMU)-based systems to provide a more comprehensive biomechanical assessment of ball release mechanics across all bowling phases.
5. **Small sample size –** The relatively small sample size of 12 male university-level fast bowlers limited the statistical power of the study and may restrict generalizability to elite or professional cricket populations. Future research should include larger and more diverse samples to enhance external validity and strengthen inferential reliability.
6. **Environmental variability –** Testing was conducted under standard pitch conditions but without strict control over environmental factors such as humidity, temperature, or surface friction, which could have influenced run-up velocity, traction, and overall bowling mechanics. Therefore, future research should standardize testing conditions—including surface type, different pitches, ambient temperature, and footwear—to minimize external variability and enhance the reliability and reproducibility of biomechanical measurements.
7. **Compare bowling techniques –** The study did not differentiate between front-on, side-on, and mixed bowling techniques, which may have limited the understanding of how specific action types of influence performance outcomes and injury risk. Since each technique involves distinct shoulder–hip alignments and kinetic chain patterns, their biomechanical contributions to Ball Release Speed could vary significantly. Therefore, future research should include a comparative analysis of these bowling

techniques to identify technique-specific determinants of performance efficiency and potential injury mechanisms, enabling more targeted coaching and individualized training interventions.

8. **Integrate EMG and force plate –** The study did not incorporate electromyography (EMG) or force plate analysis, which limited the ability to examine muscle activation patterns and quantify ground reaction forces during the delivery stride. Without this data, the interaction between neuromuscular coordination and lower-limb force generation could not be fully understood. Future research should integrate surface EMG with force platform measurements to provide deeper insights into muscle coordination, activation timing, and ground reaction force distribution, thereby offering a more comprehensive understanding of the kinetic and neuromuscular factors influencing Ball Release Speed in fast bowlers.

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