IOSR Journal of Sports and Physical Education (IOSR-JSPE)
e-ISSN: 2347-6737, p-ISSN: 2347-6745, Volume 11, Issue 2, (Mar. – Apr. 2024), PP 33-40
www.iosrjournals.org

The Influence of Lower Limb Biomechanics on Ball Release Speed: A Study of Cricket Fast Bowlers

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Abstract
This study aimed to find relationships between lower limb biomechanics and ball release velocity in 10 elite and 10 semi-professional male medium-fast bowlers. The two groups' lower limb kinematic and kinetic characteristics were compared. These data were obtained in a controlled laboratory environment utilising a 3D Vicon motion analysis system. Their correlations with the ball release speed were also examined. The elite bowlers showed far faster run-up speeds at back foot contact, but this difference decreased at the ball release point. The effect sizes showed moderate to substantial differences, with the elite group showing greater knee joint extension at both maximal flexion (d = 0.72) and ball release (d = 0.76), even though there were no statistically significant variations in front knee kinematics. However, only the front hip's positive power was significantly higher in the elite group; this is thought to be the result of less knee flexion following front foot impact. The importance of the hip and knee extensor muscle groups in promoting ball release speed was highlighted by a joint power analysis. This emphasises how important it is to have complete lower limb/core strength programmes that target the musculature related to both power and stability.

Keywords: *Motion Analysis, Kinematics, Kinetics, Fast-Bowling, Cricket.*

I. Introduction

Bowlers' ability to bowl quickly is influenced by a variety of elements, including kinanthropometry (Loram et al., 2005; Pyne et al., 2006; R. Portus et al., 2000; S. Glazier et al., 2000; Stockill & Bartlett, 1992), physiological composition (Hurrion & Harmer, 2003; Loram et al., 2005; Pyne et al., 2006; R. Portus et al., 2000), and technical expertise (B. C. Elliott et al., 1986; Hanley et al., 2005; Loram et al., 2005; Portus et al., 2004; S. Glazier et al., 2000; Salter et al., 2007a; Stockill & Bartlett, 1992). Regarding factors influencing the ball release speed, the latter has received the greatest attention in the literature.

There hasn't been much agreement in research yet regarding the key factors that influence ball release speed, particularly the contributions of the lower limbs. Researchers appear to have reached a consensus regarding the relationship between the front knee's extension between front foot contact and ball release(Burden & Bartlett, 1990; Phillips et al., 2010; Salter et al., 2007a; P. Worthington et al., 2013), as well as the front knee's flexion angle at ball release and ball release speed. On the other hand, there have been contradictory findings on the correlations between run-up speed and other variables and ball release speed. While many others have discovered that higher run-up speeds are related to increased ball release speed (Hanley et al., 2005; Phillips et al., 2010; S. Glazier et al., 2000; P. J. Worthington et al., 2013), Burden & Bartlett (1990) observed that lower run-up velocities are associated with increased ball release speed. Exploring the correlation between joint kinetics and ball release velocity is important due to the lack of agreement regarding the primary determinants affecting ball release speed in studies focusing solely on kinematics. Limited research examining these associations has employed isokinetic strength assessments for both concentric and eccentric muscle contractions (Loram et al., 2005; Wormgoor et al., 2010). Only Pyne et al., (2006) have demonstrated that lower body strength is a significant contribution to ball release speed; otherwise, neither of the above investigations revealed a link between lower limb strength and ball release speed. It's possible that measuring these strength variables may not accurately capture the forces involved in the delivery process. Ferdinands and colleagues (2003)only looked at joint kinetics in the trunk and upper arms to understand the dynamic interaction during cricket bowling. Examining the joint kinetics of the lower body throughout the delivery could offer a further understanding of the crucial biomechanical elements affecting ball release speed.

Wormgoor (2010) argue that comparing bowlers of different skill levels is crucial because parameters like ball release speed may not be directly comparable between less skilled and elite bowlers. Previous studies have either focused on homogeneous groups or compared groups at different stages of skill development (Phillips et al., 2010; Stockill & Bartlett, 1992). Therefore, this study aimed to investigate the connections between ball release speed and key lower limb movements in both semi-professional (SM) and elite (EL) fast bowlers. The hypothesis was that differences between the groups would primarily involve lower limb kinetic factors rather than kinematic ones, as bowling techniques can vary significantly regardless of skill level.

II. Material And Methods

Study participants

A group of twenty male medium-fast bowlers were chosen to participate in either the semi-professional (SM) or elite (EL) categories. Ten specialist bowlers (age 21.0 ± 4.0 years, height 176.4 ± 10.5 cm, weight 74.3 ± 8.2 kg) who were participating in State Association competitions and had participated in an EL programme either prior to or during the data collection made up the EL group. Ten specialist bowlers (age 20.7 ± 1.2 years, height 182.5 ± 7.6 cm, weight 77.1 ± 9.3 kg) participating exclusively at the amateur level made up the SM group. The a priori power analysis for "Means: Difference between two independent means (two groups)" (G*Power 3.1.9.2, Universität Kiel, Germany) was used to determine sample sizes.

Test and device setup

A 60 m × 25 m indoor cricket pitch was used for data collection, and it had enough space for participants to use their whole run-up and follow-through. A 12-camera (MX-3+) Vicon MX motion analysis system running at 250 Hz was used to track markers. Using a 0.9 m × 0.9 m AMTI force plate (BP900900) submerged flush with the laboratory floor, ground reaction forces (GRF) were recorded at 2000 Hz and synchronised with the Vicon camera system using the Workstation software. The popping crease was visible along the plate's centerline(figure 1).

Figure 1. Indoor practice pitch setup of testing.

Data collection

Each participant had 68 reflective markers, each measuring 12 mm in diameter, attached to various body parts including lower limbs, pelvis, torso, upper limbs, and head, as depicted in Figure 2. These markers were utilized for the static calibration trials, following the UWA Marker Set protocol (Middleton et al., 2016). The marker set was both dynamic and static, resembling the Chin and colleague (2009) model. To facilitate dynamic bowling experiments, the markers on the shoulder, ankle, and wrist joint centers were subsequently eliminated. Instead, four semi-spherical, soft foam markers were placed on both sides of the ball to accurately determine its virtual center. The set comprised various individual markers as well as triad "clusters" crafted from rigid, lightweight aluminum or partially flexible plastic. Research has shown that these triad clusters are effective in producing precise data during cricket bowling (Eftaxiopoulou et al., 2013) and in reducing measurement inaccuracies caused by skin motion (Cappozzo et al., 1995).

Figure 2. Custom marker sites on one participant's body while in anatomical standing position.

The dynamic bowling trials utilized anatomical frames of reference established through static calibration trials tailored to each participant. The ankle joint centers were determined using markers placed on the lateral malleolus of the fibula and the medial malleolus of the tibia, with the ankle joint centers defined as the midpoint between these markers. The method of identifying the medial and lateral femoral condyles of the knee was based on the "pointer" technique as described by Piazza & Cavanagh (2000).

Following Besier's guidelines (Besier et al., 2003), dynamic calibration experiments were conducted to ascertain the average helical axis of the knees and the functional hip and knee joint centers. For knee joint calibration, a closed weight-bearing squat task was employed to replicate the joint range of motion observed during cricket pace-bowling. This approach aims to simulate the displacement of the femur and tibia more realistically and applicably. The calibration exercise comprised five cycles of the half squat, with a range of motion approximately 45 degrees. The regression equation proposed by Campbell et al., (2009) was employed for determining the shoulder joint center, which was subsequently positioned with respect to the technical coordinate systems of the upper arm and acromion. This approach has been proven to minimize errors in identifying joint centers during overhead humeral motion(Campbell et al., 2009).

Each participant completed their standard bowling session warm-up after the calibration trials in an effort to simulate (physiological) match conditions as nearly as feasible.

Engaging in a warm-up routine also aided in getting accustomed to the laboratory environment and determining the starting position for the run-up. After the warm-up, every player was instructed to bowl five sets of six deliveries, simulating match intensity, with the target being a cross positioned outside and above the off-stump (Figure 1). Previous studies have shown no evidence of a decline in bowling speed during 12-over bowling sessions (Burnett et al., 1995; R. Portus et al., 2000).

The Vicon Workstation software was utilized to capture two-dimensional data from all 12 cameras for each marker, and subsequently, the trajectories of the markers were reconstructed in 3D. To address any discontinuities or missing segments in marker trajectories, cubic spline interpolation was employed. A trial was considered unsuitable for analysis if there existed a gap exceeding 25 frames. Subsequently, both marker and GRF data underwent filtering at a frequency of 20 Hz using a dual-pass second-order low-pass Butterworth filter. The choice of this filter was determined through residual analysis conducted with a customized MATLAB script, supplemented by visual inspection. The UWA model (Middleton et al., 2015) within the Vicon Workstation pipeline was employed for data modeling. Throughout the dynamic trials, encompassing from the impact of the back foot to the release of the ball, kinematic and kinetic measurements were taken, while anthropometric data was derived from each participant's calibration trial. The kinematics of ball motion were measured after the ball release.

Following Grood & Suntay (1983) and Wu et al. (2002, 2005), joint angles were expressed using the standard Euler Z-X-Y convention. The rotations of the child segment coordinate system concerning the parent segment coordinate system followed the following order: flexion–extension, abduction–adduction, and internal/external. Three basic articulations were identified: abduction–adduction around the floating axis perpendicular to the z- and y-axes, pronation–supination around the y-axis of the moving segment, and flexion–extension around the z-axis of the fixed segment.

Various kinematic and kinetic parameters were analyzed, including stride length, run-up speed, knee flexion–extension angle, hip and knee joint kinetics, and GRFs. The moments of impact of the back foot and front foot were determined by a vertical GRF threshold of 20 N. The moment of ball release was identified as the initial frame where the distance between the center of the ball and the carpal marker exceeded 15 cm. The speed of ball release was computed as the instantaneous speed of the virtual ball center at the point of release. Stride length was determined as the length of the hypotenuse created using the differences between the global x and y coordinates of the left ankle joint center at the back foot impact (BFI) and the right ankle joint center at the front foot impact (FFI). Run-up speed was evaluated as the instantaneous speed of the body's center of mass at the moments of BFI and ball release.

Several kinetic parameters were analyzed in the study, including moments and powers of the hip and knee joints, along with peak GRFs in various directions. The analysis employed standard inverse dynamic techniques to calculate joint moments and powers, incorporating participant-specific segment inertial properties as per De Leva (1996). Notably, utilizing a non-orthogonal joint coordinate system, as reported by Schache & Baker (2007), revealed a greater clinical significance in lower limb moments. Although the usefulness of power has been debated by some (Adamson & Whitney, 1971; Knudson, 2009), time and power statistics were included for comparison with prior research. Additionally, all kinetic variables were normalized by each participant's body weight.

Due to the quality of the data, an average of 17 to 20 deliveries was selected for analysis per participant. A comparison between the SM and EL groups was conducted using independent sample t-tests. The association between ball release speed and various anthropometric, kinematic, and kinetic factors was assessed using Pearson product-moment correlations. Following Cohen's guidelines (1992), correlation coefficients (r) of 0.1 were considered weak, 0.3 moderate, and 0.5 high. The significance level was set at 0.05. Effect sizes were computed, as suggested by Cohen (1992), to address functional differences between groups, with values of 0.2, 0.5, and 0.8 indicating modest, medium, and large effect sizes, respectively.

III. Results

Demography

Regarding any demographic feature, there were no significant differences between the SM and EL groups (Table 1).

Table 1. Demographic data of both groups in mean (±SD).

Variable	**Semi-professional**	**Elite**	**p-value**
Age (in years)	20.7 (1.2)	21.0 (4.0)	0.112
Height (in cm)	182.5 (7.6)	176.4 (10.5)	0.139
Weight (in kg)	77.1 (9.3)	74.3 (8.2)	0.635

Kinematics

With a mean difference of 3.6 m/s, the EL group bowled far faster than the SM group (Table 2). There was no difference in the groups' absolute stride length or stride length as a percentage of standing height. upon BFI, the EL group showed a significantly greater centre of mass speed; however, this difference became insignificant upon ball release. For the duration of the back foot contact period, the two groups' back knee kinematics were similar. Although differences neared significance for levels of maximal knee flexion and knee flexion angle at ball release, combined with moderate-high effect sizes, front knee angles at FFI were also equal (Table 2).

Table 2. Selected kinematic variables' comparisons and group means (±SD).

	Semi-professional		Elite		Comparison	
Kinematic variables	Mean (SD)	Correlation to ball release speed (r)	Mean (SD)	Correlation to ball release speed (r)	p-value	Effect size
Ball release speed (m/s)	26.6 (1.8)		30.2 (1.8)		<0.001*	2.28
Stride length (mm)	1235.8 (192.6)	0.279	1332.6	-0.007	0.108	0.58
Stride length (% of height)	72.5 (7.9)	0.202	71.6 (8.3)	-0.123	0.158	0.59
Centre of mass speed (@BFI) (m/s)	4.2 (0.8)	0.225	5.5 (0.7)	0.556*	0.024*	1.00
Centre of mass speed (@BR) (m/s)	2.1 (0.7)	0.021	2.5 (0.5)	0.411	0.058	0.61
Back knee flexion angle (BFI) (°)	38.9 (11.7)	-0.166	45.9 (10.8)	-0.096	0.231	0.48
Max back knee angle (@BFI to FFI) (°)	66.4 (8.6)	0.349	71.6 (11.2)	-0.028	0.576	0.22
Back knee flexion range	27.8 (10.9)	0.398	22.7 (12.3)	0.058	0.493	0.29

(Max—BFI) (°)						
Front knee flexion angle (@FFI) (°)	17.2 (5.2)	-0.031	16.8 (7.1)	-0.125	0.952	0.04
Max front knee flexion (FFI to BR) (°)	45.2 (13.3)	-0.535*	35.9 (12.8)	0.096	0.067	0.75
Front knee flexion angle (@BR) (°)	43.1 (18.2)	-0.606*	25.3 (23.1)	0.152	0.051	0.74

*sig. difference/correlation (p<0.05)

BFI. Back foot impact; BR. Ball release; FFI. Front foot impact; Max. Maximum. Pearson's product–moment correlation coefficients (r) are reported between selected kinematic variables and ball release speed.

In the study, it was observed that in theEL group, a greater velocity of ball release was linked to an increased pace of the run-up at the moment of impact on the back foot. Conversely, in the SM group, a significant inverse relationship was identified between the angle of flexion in the front knee at the point of ball release and the maximum speed of flexion in the front knee. These findings highlight different patterns in the mechanics of bowling between elite and semi-professional cricketers.

Kinetics

The only kinetic characteristic that differed statistically across groups was positive hip power (p = 0.006). The modest effect sizes (Table 3) indicated a tendency for the EL group to create higher front knee positive power, front hip extension moment, and front hip negative power. For the SM group, there was a significant relationship between peak front knee positive power and ball release speed. The EL group exhibited a considerably larger vertical force (perpendicular to ground) and anterior-posterior (parallel to pitch) force. Although there was no significant difference in the medial-lateral GRF across the groups, there was a significant high effect size and a negative correlation between ball release speed and the EL group.

Table 3. Selected kinetic variables' comparisons and group means (±SD).

Kinetic variables	Semi-professional		Elite		Comparison	
	Mean (SD)	Correlation to ball release speed (r)	Mean (SD)	Correlation to ball release speed (r)	p-value	Effect size
Front knee extension moment (Nm/kg)	-2.7 (2.9)	-0.236	-2.9 (1.8)	-0.327	0.644	0.15
Front knee negative power (W/kg)	-41.6 (22.7)	0.208	-48.2 (36.9)	-0.366	0.591	0.18
Front knee positive power (W/kg)	9.5 (10.4)	0.546*	14.7 (9.2)	-0.086	0.087	0.65
Front hip extension moment (Nm/kg)	-5.3 (1.4)	-0.478	-6.5 (2.1)	0.303	0.102	0.55
Front hip negative power (W/kg)	-26.7 (14.2)	-0.438	-36.8 (12.4)	0.349	0.072	0.66
Front hip positive power (W/kg)	23.9 (10.1)	0.123	39.4 (17.4)	0.000	0.006*	1.08
Medial-lateral ground reaction force (N/kg)	0.1 (0.1)	0.233	0.1 (0.1)	-0.651*	0.214	0.45
Anterior-posterior ground reaction force (N/kg)	2.2 (0.5)	0.448	2.7 (0.6)	0.433	0.002*	1.27
Vertical ground reaction force (N/kg)	3.6 (0.8)	0.477	4.4 (0.7)	0.329	0.003*	1.32

*sig. difference/correlation (p<0.05)

Pearson's product– moment correlation coefficients (r) are reported between selected kinematic variables and ball release speed.

IV. Discussion of findings

The aim of this study was to examine the differences in lower limb kinematic and kinetic factors between EL and SM fast bowlers, as well as their relationship with ball release speed, considering that faster bowlers tend to be more successful (Elliott et al., 2005). The EL bowlers demonstrated significantly higher bowling speeds compared to the SM group. They exhibited significantly greater center of mass speed than the SM group upon BFI, and although the difference was not statistically significant at release, the substantial effect size suggests a functional difference. Ferdinands and colleagues (2010)proposed that bowlers who can decelerate during their delivery may achieve higher ball release speeds. This study's findings align with this proposition, as the differences in center of mass speed between the two groups decreased throughout the delivery stride, from BFI to ball release. Moreover, center of mass speed at BFI was correlated with ball release speed for the EL group, supporting the findings of Salter et al. (2007)in their analysis within bowlers, although differing from their between-bowlers data.

Based on some coaching material (Hurrion & Harmer, 2003), it was suggested that bowlers experience a loss of momentum and a likely decrease in their center of mass speed when they flex their back knee following a BFI, until the ball is released. However, subsequent analysis indicated no significant correlation (p = 0.41) between the range of back knee flexion and the shift in center of mass speed from back foot contact to ball release. Both groups in the study landed with bent knees at rear foot impact and maintained this position until FFI. The maximum back knee flexion observed in both groups and the extent of back knee flexion at BFI matched the findings reported by Phillips and colleagues (2010). While no correlations were found in the present study, significant associations were noted by those researchers between the back knee angles mentioned earlier and the speed at which the ball is released. Therefore, the impact of back knee flexion on ball release speed remains uncertain.

The front knee kinematics upon FFI were comparable between the two groups, as indicated by similar measurements. However, despite lacking statistical significance, the moderate to high effect sizes implied functional differences in front knee movements post FFI. Following FFI, the SM group exhibited approximately a 10° greater flexion in the front knee compared to the EL group. Consequently, the SM group could only extend the front knee by 3° prior to ball release, whereas the EL group managed a 10° extension. This variation in knee flexion aligns with the observations of Bartlett et al. (1996), who found no evident variations in knee flexion among elite, club, and novice javelin throwers post FFI, with a tendency for more skilled throwers to exhibit lesser flexion. Therefore, it appears that the EL group demonstrated greater resilience to ground forces upon front foot landing compared to the SM group (Worthington et al., 2013). Notably, significant negative correlations were observed between both the maximum front knee flexion angle and front knee angle at ball release with ball release speed. This finding aligns with the assertions of various authors (Davis & Blanksby, 1976; B. C. Elliott et al., 1986; B. C. Elliott & Foster, 1984; P. Worthington et al., 2013) suggesting that bowling over a straightened front limb enables the bowler to utilize it as a lever and fixed pivot, thereby potentially aiding in the maintenance of total body angular momentum.

Further investigation showed that there was a significant association between the velocity of the run-up and the angle of the front knee at the moment of ball release for the SM group (r = 0.518, p = 0.058), while this association was statistically significant for the EL group (r = 0.749, p = 0.001). These findings imply that flexing the front knee subsequent to the impact of the front foot contributes to the preservation of linear momentum. A more detailed analysis of the correlation between the maximum angle of the front knee and the run-up speed at ball release revealed a significant relationship for both the SM (r = 0.551, p = 0.041) and EL (r = 0.695, p = 0.004) groups. Despite its potential benefits, it is important to note that bowlers exhibiting a higher deceleration of their body's center of mass during the delivery stride might possess the capability to achieve higher bowling speeds, as highlighted by Ferdinands and colleagues (2010). The flexion of the knee after the impact of the front foot could potentially restrict the bowler's capacity to generate angular momentum in their upper body. It is imperative for cricket coaches to recognize that rapidly decelerating the body's center of mass is equally crucial for enhancing ball speed as having a swift run-up. These findings reinforce the idea that employing a flexor–extender knee action is optimal, as it not only disperses GRFs (P. Worthington et al., 2013) but also facilitates the conservation of both linear and angular momentum. This is achieved by flexing the knee during the front foot contact phase to reduce braking forces (Portus et al., 2004), followed by extension to decelerate the speed of the body's center of mass, thus aiding in the transfer of energy to the trunk and bowling arm (Ferdinands et al., 2010). However, akin to the knee actions described by Portus et al. (2004), only a minority of the sample, approximately 10%, utilized this 'optimal' flexor–extender technique.

The kinetic observations concerning the knee and hip joints in the delivery stride indicate a distinct "support" phase marked by extension moments in both joints. This phase is characterized by knee flexion following FFI, leading to negative powers in both the knee and hip joints. Subsequently, as both groups extend the front knee before ball release, positive powers in these joints indicate a corresponding "drive" phase similar to running (Novacheck, 1998). The knee extension moments observed during delivery were similar to those measured isokinetically for peak knee concentric extension moment byLoram et al. (2005) and peak knee eccentric torque by(Wormgoor et al., 2010). Interestingly, only hip positive power was significantly increased in the EL group, partially supporting the hypothesis of greater lower limb kinetics in this group. Future studies on lower limb kinetics during fast bowling should consider participants' knee actions before statistical comparisons. The absence of noticeable differences may also stem from the EL group utilizing a lower proportion of their maximum voluntary contractile strength in the lower limbs. To investigate deeper into the relationship between joint kinetics and performance variables, researchers should aim to assess both kinetics during dynamic activity and isokinetic strength measures to assess performers' absolute strength capabilities. Notably, front knee positive power correlated with ball release speed in the SM group, validating the kinematic findings of this study that bowlers who extend their front knee before ball release can achieve higher ball release speeds.

The peak medial-lateral value for the EL group was negatively correlated with ball speed. The GRFs that the study's participants encountered were similar to those described in the literature (Foster et al., 1989; Foster & Elliot, 1985; Portus et al., 2004; P. J. Worthington et al., 2013). As a result, bowlers with higher EL were more stable when making medial-lateral contact with the ground. According toWorthington and colleagues (2013), faster bowlers have more linear momentum at impact and then produce high peak forces during the body's deceleration phase. This interpretation is supported by the higher vertical and anterior-posterior GRFs of the EL group, which can be explained by the higher centre of mass speed and subsequent deceleration. Additionally, MacWilliams and (1998)found strong associations between anterior-posterior (r^2 = 0.86) and vertical landing force (r^2 = 0.70) and linear wrist speed.

The study's findings emphasise the necessity of multifaceted conditioning methods that concentrate on the muscles linked to both stability and power. To transfer energy from the lower limbs to the trunk and bowling arm, bowlers need to be able to generate power through their muscles to stabilise their pelvis and trunk during the transition from the run-up to the back foot contact phase (Ferdinands et al., 2003). Ball release speed may be affected if the body is unstable during this stage, especially in the medial-lateral direction.

Even though the EL group in this study participated in specialised training, a comparison of semi-professional and elite (national or state level) bowlers would show a stronger difference in skill development. The kinematic and kinetic differences between more and less competent bowlers, as well as the correlations between these variables and ball release speed, may be better understood in light of this wider inequality. According to Salter et al., (2007b), group-based studies have inherent limitations as well. One such restriction is the inability to control factors other than bowling technique that may affect ball release speed. However, some of the study's findings have demonstrated strong agreement with previous studies employing group-based analyses, indicating that it is possible to draw confident conclusions regarding variables influencing ball release speed even at the group level.

V. Conclusion

The primary objectives of this investigation were to assess the comparative lower limb kinematic and kinetic parameters and their associations with ball release velocity among EL and SM fast bowlers. It was observed that the EL group exhibited a significantly higher bowling speed compared to the SM counterparts, alongside greater center of mass velocity upon BFI. Consistent with expectations, no variances were detected in lower limb kinematics across the groups. However, remarkable effect sizes for metrics such as maximum front knee flexion and front knee flexion angle at ball release indicate that EL bowlers demonstrated improved capacity to sustainhigher braking forces and vertical GRFs. Interestingly, only hip positive power exhibited a significant increase in the ELgroup, possibly stemming from their reduced knee flexion post FFI, enabling greater utilization of hip musculature compared to the SM group. Investigation of correlations between front knee kinematics and kinetics with ball release speed underscored the significance of strong hip and knee extensor strength in facilitating ball speed generation. Furthermore, a negative correlation between ball release speed and peak medial-lateral GRF within the EL group suggested that an imbalance in medial–lateral weight distribution over the front foot might obstruct the development of ball speed among EL bowlers.

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