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To cite this article: Hamish Bull, Peter Alway, Paul Felton & Mark King (17 Feb 2026): The influence of the pre-delivery stride on subsequent fast bowling technique in elite male cricketers, Journal of Sports Sciences, DOI: [10.1080/02640414.2026.2631333](https://doi.org/10.1080/02640414.2026.2631333)

To link to this article: <https://doi.org/10.1080/02640414.2026.2631333>



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Published online: 17 Feb 2026.



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The influence of the pre-delivery stride on subsequent fast bowling technique in elite male cricketers

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ABSTRACT

Research in cricket fast bowling has primarily investigated technique from back foot contact onwards. This study aims to explore the effect of the pre-delivery stride (step pre-back foot contact) on technique characteristics previously linked with performance and injury risk. Six pre-delivery stride, and 16 performance or lumbar bone stress injury-related technique characteristics were determined for 29 elite male fast bowlers. Fifteen significant correlations were observed between the pre-delivery stride and the performance and injury-risk characteristics ($p < 0.05$). From a performance perspective, greater pre-delivery run-up velocity and lower take-off angles were associated with increased front leg plant angles at front foot contact and knee flexion at ball release. From an injury perspective, greater anterior pelvic tilt at take-off, jump height, and landing vertical velocity at back foot contact were associated with more flexed rear leg kinematics at back foot contact and anterior pelvic tilt at front foot contact. These findings suggest individual-specific pre-delivery stride run-up velocities and take-off angles exist to synchronously optimise technique to enhance performance and reduce injury risk. This knowledge is essential for enhancing the coaching and rehabilitation of fast bowlers, supporting coaches to account for the effect of the pre-delivery stride on subsequent fast bowling technique.

ARTICLE HISTORY

Received 7 August 2025
Accepted 5 February 2026

KEYWORDS

Cricket; performance; injury; gather; ball release speed; lumbar stress injuries

Introduction

Fast bowling in cricket is a multiphasic skill in which bowlers run-up and deliver a ball at high speeds (32.8–39.7 m/s) towards a batter attempting to intercept the ball and score runs (Bhandurje et al., 2024; Worthington et al., 2013). One strategy adopted by fast bowlers is to deliver the ball as quickly as possible to reduce the time batters have to react and play an appropriate shot, increasing the likelihood of taking a wicket and reducing run scoring opportunities (Zhang et al., 2011). Whilst bowling accuracy and consistency are also recognised as key factors important for bowling success (Petersen et al., 2008), the ability to generate high ball speeds remains the defining characteristic of fast bowling.

The bowling action has previously been split into three distinct phases: a run-up, a pre-delivery stride, and a delivery stride (see Figure 1; Glazier & Wheat, 2014a). The run-up is defined as the phase between the start of the bowler's approach until the moment of take-off prior to the pre-delivery stride and is used by bowlers to develop linear momentum which can be utilised during the delivery stride (Glazier & Worthington, 2014b; Kiely et al., 2021). The pre-delivery stride, otherwise known as

the “gather” or the “bound” in coaching literature (Woolmer et al., 2008), is the penultimate step or step before back foot contact and is the phase between the take-off at the end of the run-up and the instance of back foot contact (BFC) (Bartlett et al., 1996; Glazier & Wheat, 2014a). Scientific understanding of the pre-delivery stride is limited with the bulk of the knowledge of this phase coming from player experience or coaching literature (Glazier & Wheat, 2014a). The final phase of fast bowling is the delivery stride, defined as the phase between BFC and ball release (BR), and is generally considered as the phase where the key actions responsible for determining ball release speed occur (Glazier & Wheat, 2014a).

Research exploring the effect of the technique on performance has identified multiple characteristics associated with faster ball release speeds including faster run-up speeds, more extended front-leg knee angles at front foot contact (FFC) and BR, greater thoracolumbar flexion between FFC and BR, and less bowling shoulder extension (delayed arm circumduction) at FFC (Bhandurje et al., 2024; Worthington et al., 2013). These findings are consistent with other experimental studies (Duffield et al., 2009; Ferdinands et al., 2010; Kiely et al., 2021) and

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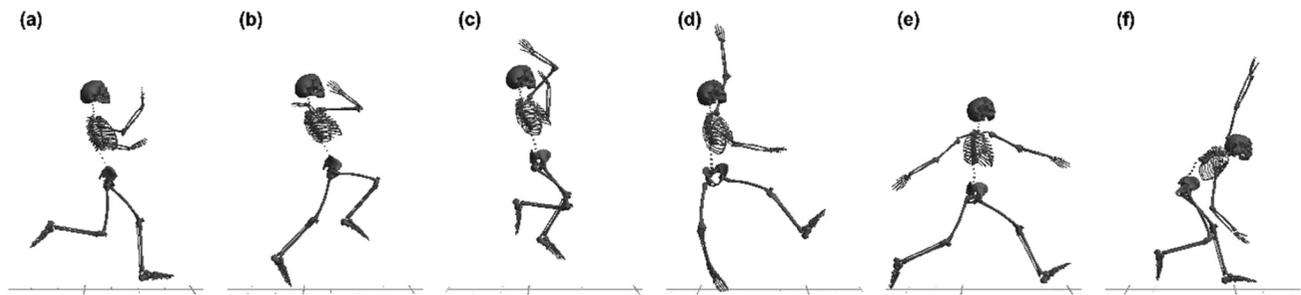


Figure 1. Visualisation of pre-delivery stride (a: penultimate step; b: penultimate step take-off; c: pre-delivery stride flight; d: back foot contact) and delivery stride (d: back foot contact; e: front foot contact; f: ball release).

a theoretical approach which investigated optimal technique via forward dynamics (Felton, McCaig, et al., 2023). In addition, larger front leg plant angles at FFC (King et al., 2016) and greater whole-body centre of mass (COM) deceleration between BFC and FFC, as well as between FFC and BR (Ferdinands et al., 2010) have also been correlated with increased ball release speeds. Besides run-up velocity, most of the technique characteristics associated with performance occur during the delivery stride. Although research has considered how the pre-delivery stride may influence these subsequently occurring technique characteristics associated with performance (Kiely et al., 2021), it is currently unknown how these characteristics are influenced by the pre-delivery stride.

Studies investigating the link between fast bowling technique and injury have commonly focused on lumbar bone-stress injuries (LBSI). These are the most prevalent injury in cricket and occur nearly exclusively to fast bowlers (Orchard et al., 2016). LBSIs are an overuse injury caused by the accumulation and propagation of microdamage across bone (Hoening et al., 2022) and are typically observed in fast bowlers at the pars interarticularis or pedicle of L4 or L5 on the opposing side to the bowling arm (Alway et al., 2019). While LBSIs are multifactorial (Hoening et al., 2022), Alway et al. (2021) demonstrated that two technique characteristics (rear hip flexion at BFC and lumbopelvic extension at FFC) could successfully classify 88% (injured: 97%; uninjured: 55%) of prospective LBSI injuries in elite fast bowlers over a 2-year period. In addition, significant differences in front hip flexion at FFC, pelvic tilt at FFC, thoracolumbar rotation at BFC, thoracolumbar side flexion at BFC and BR, and rear knee flexion at BFC were observed between bowlers who did and did not prospectively suffer an LBSI. It was suggested that bowlers may adopt more flexed rear leg kinematics at BFC due to the need to produce the increased torque available at the mid-range of the joint to redirect the bowler's COM post BFC (Alway

et al., 2021; Thorstensson et al., 1976). Although this may indicate a link between the pre-delivery stride and subsequent technique, exploration of how LBSI associated technique characteristics are influenced by the pre-delivery stride is yet to be conducted.

Despite widespread research on fast bowling technique from a performance and injury perspective, research investigating the influence of the pre-delivery stride on subsequently occurring technique characteristics associated with performance and LBSI risk is scarce. This investigation is exploratory in nature, therefore no hypothesis is posed. This study aims to explore the effect of the pre-delivery stride (step prior to back foot contact) on fast bowling technique characteristics previously linked with performance and LBSI risk.

Method

Participants

A *a priori* power analysis was conducted (G*Power 3.1.9.4) for a two-tailed bivariate normal model correlation ($H_1 r = 0.5$, $\alpha = 0.05$, $1 - \beta$ error probability = 0.8) which determined a required sample size of 29 (Faul et al., 2007). The effect size was selected considering findings from previous literature (Ferdinands et al., 2010; Kiely et al., 2021; King et al., 2016). Data were retrospectively collated from 29 elite male cricket fast bowlers (age: 22.46 ± 3.78 , height: 1.86 ± 0.07 m, mass: 85.15 ± 10.66 kg) from a historical dataset that had good-quality data (e.g., in target volume and minimal marker loss) from prior to pre-delivery stride take off to ball release and was previously used in the studies of Worthington et al. (2013) and Alway et al. (2021). All bowlers provided written informed consent to participate in accordance with the guidelines of the Loughborough University Ethics Advisory Committee (R16-P110) and were deemed fit to bowl by a qualified physiotherapist.

Data collection

Each bowler performed a minimum of six maximal velocity deliveries on a 'good length' in an indoor full length artificial practice facility with kinematic data of each delivery collected using an 18-camera Vicon Motion Analysis System (OMG Plc, Oxford, UK) recording at 300 Hz. All participants completed a thorough self-directed warm-up prior to data collection. Forty-seven 14-mm retro-reflective markers were attached to bony landmarks on each fast bowler in accordance with a full-body marker set developed for analysing cricket fast bowling (Worthington et al., 2013). A 2-cm square piece of reflective tape was attached to the ball so ball release velocities could be calculated, and the instance of ball release identified. A static trial with the participant standing in an anatomically neutral position, and a trunk lateral range of motion trial where the bowler maximally side flexed to both the contralateral and ipsilateral sides (in respect to the bowling arm), were recorded. This allowed body segment lengths and neutral spine positions to be calculated (Ranson et al., 2008). Ninety-five anthropometric measurements were also taken enabling bowler-specific segmental inertial parameters, and subsequently COM velocity, to be determined for each bowler (Yeadon, 1990).

Data processing

To maintain ecological validity regarding the investigation of movement patterns associated with optimal performance, the fastest trial for each bowler with minimal marker loss was reconstructed and manually labelled using Vicon's Nexus software (OMG Plc., Oxford, UK) prior to being processed in MATLAB R2021a (The MathWorks, MA, USA). All marker trajectories were filtered using a recursive fourth-order low pass Butterworth filter at 30 Hz identified via residual analysis (Winter, 1990). Joint centres for the ankle, knee, elbow, wrist and shoulder were calculated as the mid-point between pairs of mediolateral markers (anterior-posterior for shoulder) placed on each joint (King et al., 2016; Ranson et al., 2008; Worthington et al., 2013). Hip joint centres were calculated using markers on the left and right anterior and posterior superior iliac spine and a leg length measurement (Davis et al., 1991). The thoracolumbar junction was defined as the midpoint between the xiphoid process and L1 spinous marker while the lumbopelvic junction was defined as the midpoint between the posterior superior iliac spine markers (Worthington et al., 2013).

Penultimate step contact (PSC; Figure 1a), BFC (Figure 1d) and FFC (Figure 1e) were determined using

visual inspection of foot marker displacements, with ground contact being defined as the first frame where a foot marker trajectory changed due to the impact with the ground. The end of the ground contact phases or 'toe-off' events (penultimate step take-off – PSTO; Figure 1b) were determined using the foot markers as the first frame where the vertical displacement of the toe markers exceeded their mean position in the static trial. BR was identified as the first frame where the distance between the ball marker and wrist joint centre changed by more than 20 mm relative to the previous frame (Worthington et al., 2013).

The global coordinate system was defined with the y-axis pointing down the wicket in the direction the bowler was running, the x-axis perpendicular to the y-axis to the bowler's right-hand side, and the z-axis vertically upwards (Worthington et al., 2013). Three-dimensional local reference frames were identified for an 18-segment full-body model comprising a head and neck, thoracic and lumbar spine, pelvis and two upper arms, forearms, hands, upper legs, lower legs and two-segment feet. The local reference frame for each segment was orientated to be aligned with the global reference frame in the anatomical position. Joint angles were calculated as cardan angles with the xyz rotations corresponding to flexion-extension, abduction-adduction and longitudinal rotation, respectively. Angles were determined describing the front knee (extended = 180°, flexed < 180°), hip (extended = 180°, flexed < 180°), sagittal plane pelvis tilt (anterior tilt < 180° < posterior tilt), lumbopelvic and thoracic spine (flexion and contralateral, away from bowling arm, side flexion and rotation < 180°, extension and ipsilateral side flexion and rotation > 180°), bowling arm (anatomical position viewed in sagittal plane = 0°, >180° corresponds to shoulder flexed behind trunk in sagittal plane) and front leg plant angles (0° < larger plant angle with ankle more anterior relative to hip joint centre; Worthington et al., 2013). Ball release speed was calculated as the mean ball marker velocity over 10 frames (0.033 s) post BR, and run-up velocity was defined as the mean horizontal (anterior-posterior) whole-body COM velocity over the 18 frames (0.06 s) prior to PSC (Figure 1a) and BFC (Figure 1d) (Worthington et al., 2013).

Data analysis

Six pre-delivery stride characteristics, eight technique characteristics previously associated with performance and eight technique characteristics previously associated with LBSIs were calculated and put forward for analysis. Pre-delivery stride characteristics were identified based on their potential to influence subsequent bowling technique or had been considered in the

previous research. The six characteristics: jump height (vertical COM displacement from its average prior to PSC; absolute and normalised to bowler's height), pre-delivery stride length (anteroposterior displacement of the foot COM at PSC from the contralateral foot COM position at BFC; absolute and normalised to bowler's height), landing velocity at BFC (vertical COM velocity at BFC), penultimate step take-off angle (angle of the COM linear in the sagittal plane relative to the horizontal at PSTO), run-up velocity pre-jump (average horizontal COM velocity 18 frames/0.06 s prior to and inclusive of PSC), and pelvic tilt at PSTO (anterior-posterior orientation of the pelvis segment). The previously identified performance-related characteristics were ball release speed, run-up velocity front knee angle (at BR), thoracolumbar flexion between FFC and BR (change in flexion angle between thorax and lumbar segments), bowling shoulder angle (at FFC), front leg plant angle at FFC (angle in sagittal plane between hip and ankle joint centre vector relative to the horizontal), and the whole-body COM acceleration within two phases: the pre-delivery stride contact phase (Figure 1(e)) and delivery stride contact phase (Figure 1(e-f)) (Ferdinands et al., 2010; King et al., 2016; Worthington et al., 2013). The eight LBSI-related technique characteristics calculated were those identified by Alway et al. (2021): front hip angle (at FFC), pelvic tilt (at FFC), thoracolumbar rotation (at BFC), lumbopelvic angle (at FFC), rear hip angle (at BFC), rear knee angle (at BFC) and thoracolumbar side flexion (at BFC and BR).

Statistical analyses were conducted within Statistical Package for the Social Sciences v.27 (SPSS Corporation, USA). Normality was assessed using a Shapiro-Wilks test and assumption of equal variances using a Levene's test. Bivariate correlations were run using a two-tailed Pearson's product moment coefficient to examine relationships between pre-delivery stride technique characteristics and previously identified performance and LBSI-related technique characteristics. Alternatively, a Spearman's rank test was used if normality was violated. An alpha value of 0.05 was used to determine significance. No adjustment for multiple comparisons was made due to the risk of increasing the occurrence of type 2 errors (Sinclair et al., 2013).

Results

The 29 bowlers in this study produced ball release speeds in the range of 32.8–38.5 m/s. Descriptive statistics of the pre-delivery stride technique characteristics,

and those previously associated with performance and injury (Table 1).

Ball release speed was not found to correlate with any pre-delivery stride characteristics (Table 2; $r = -0.134$ – 0.260 ; $p = 0.170$ – 0.984). Nine significant correlations were identified between the pre-delivery stride and performance-related technique characteristics (Table 2). Greater penultimate step take-off angles (more vertical) were correlated with lower front leg plant angles ($r = -0.428$, $p = 0.021$) and slower run-up velocities at BFC ($r = -0.400$, $p = 0.032$). Larger normalised penultimate step lengths were associated with faster run-up velocities at BFC ($r = 0.505$, $p < 0.001$) and increased knee flexion at BR ($r = -0.436$, $p = 0.018$). Pre-delivery stride run-up velocity was correlated with four performance characteristics: greater horizontal front leg plant angles ($r = 0.524$, $p = 0.004$), increased knee flexion at BR ($r = -0.382$, $p = 0.041$), greater deceleration during FFC phase ($r = -0.401$, $p = 0.031$), and faster run-up velocity at BFC ($r = 0.844$, $p < 0.001$). Lower vertical landing velocity at BFC (greater downwards) was correlated with reduced thoracolumbar flexion ($r = 0.372$, $p = 0.047$), and greater bowling shoulder flexion (less delayed arm circumduction) at FFC ($r = 0.379$, $p = 0.043$).

Six significant correlations were identified between the pre-delivery stride and LBSI-related technique characteristics (Table 3). Larger normalised jump heights, and greater vertical take-off angles, were associated with increased anterior pelvic tilt at FFC ($r = 0.472$, $p = 0.010$; $r = 0.449$, $p = 0.014$, respectively). Greater landing velocity at BFC was associated with greater flexion of both the rear hip ($r = 0.479$, $p = 0.009$) and knee ($r = 0.401$, $p = 0.031$). Similarly, greater anterior pelvic tilt at take-off correlated significantly with increased rear hip ($r = -0.716$, $p < 0.001$) and knee flexion ($r = 0.447$, $p = 0.015$) at BFC.

No other pre-delivery stride characteristics were associated with technique characteristics previously associated with ball release speed or LBSI injury.

Discussion

This study aimed to explore the effect of the pre-delivery stride on fast bowling technique characteristics previously linked with performance and LBSI risk in elite male cricket fast bowlers. Although no significant relationships were identified between any pre-delivery stride characteristics and ball release speed, multiple pre-delivery stride characteristics were correlated with technique characteristics previously associated with

Table 1. Range, mean and standard deviations for the pre-delivery, and subsequent performance and injury-related technique characteristics.

Technique characteristics	Range	Mean \pm SD
<i>Pre-delivery stride</i>		
Jump height (m)	1.11–1.40	1.27 \pm 0.07
Jump height normalised (%)	60.4–76.5	68.0 \pm 3.80
Penultimate step length (m)	1.73–3.00	2.27 \pm 0.32
Penultimate step length normalised (%)	92.2–162	122 \pm 18
Run-up velocity pre-jump (m/s)	4.71–7.26	6.00 \pm 0.60
Landing velocity BFC (m/s)	–1.99–0.89	–1.42 \pm 0.30
Take-off angle (°)	5–17	11 \pm 3
Pelvic tilt PSTO (°)	155–195	174 \pm 8
<i>Performance</i>		
Ball speed (m/s)	32.7–38.5	35.4 \pm 1.33
Front leg plant angle FFC (°)	27–44	38 \pm 4
Run-up velocity BFC (m/s)	5.09–7.04	5.87 \pm 0.53
Front knee angle BR (°)	133–196	177 \pm 17
Thoracolumbar flexion (FFC-BR) (°)	18–48	31 \pm 7
Bowling shoulder angle FFC (°)	205–334	255 \pm 35
Average acceleration BFC phase (m/s ²)	–5.97–1.12	–3.49 \pm 1.37
Average acceleration FFC phase (m/s ²)	–19.5–4.73	–12.9 \pm 3.16
<i>LBSI</i>		
Front hip angle FFC (°)	115–150	130 \pm 9
Pelvic tilt FFC (°)	157–185	168 \pm 6
Thoracolumbar rotation BFC (°)	170–187	178 \pm 4
Lumbopelvic angle FFC (°)	169–196	177 \pm 6
Rear hip angle BFC (°)	124–172	147 \pm 13
Rear knee angle BFC (°)	115–171	151 \pm 13
Thoracolumbar side flex BR (°)	157–170	163 \pm 4
Thoracolumbar side flex BFC (°)	172–196	182 \pm 5

SD: Standard deviation; normalised values are relative to participants standing height; BR: ball release; BFC: back foot contact; FFC: front foot contact; PSTO: penultimate step take-off.

performance and LBSI risk. These findings suggest that due to the multiphasic nature of fast bowling, that post-BFC fast bowling technique associated with increased performance and LBSI risk may be affected by the pre-delivery stride.

Performance-related effects

The best individual predictor of a performance-related technique characteristic in this study was pre-jump run-up velocity which had a strong correlation with run-up velocity at BFC ($r = 0.844$; Table 2). Run-

up velocity at BFC has previously been reported to be the most important predictor of ball release speed in fast bowling (Worthington et al., 2013). Faster run-ups have been suggested to provide greater linear momentum to be available at FFC, which can be transferred during the delivery stride into angular momentum and ultimately into the ball resulting in faster ball speeds (Worthington et al., 2013). While this relationship was expected, since the run-up occurs prior to the pre-delivery stride, the strength of the correlation ($r = 0.844$) suggests that individual variability exists in the maintenance of horizontal

Table 2. Pearson/Spearman correlation coefficients between pre-delivery stride kinematics and key performance-related technique characteristics.

	Jump height (normalised)	Take-off angle	Penultimate step length (normalised)	Run-up velocity (pre-jump)	Landing velocity (BFC)	Pelvic tilt (PSTO)
<i>Performance characteristics</i>						
Ball speed (m/s)	–0.004	–0.134	0.290	0.262	–0.124	–0.047
Front leg plant angle FFC (°)	–0.166	–0.428*	0.236	0.524*	–0.006	–0.261
Run-up velocity BFC (m/s)	–0.074	–0.400*	0.505*	0.844*	–0.159	0.311
Front knee angle BR (°)	–0.347	–0.059	–0.436*	–0.382*	0.262	0.170
Thoracolumbar flexion (FFC-BR) (°)	–0.278	–0.128	–0.137	0.187	0.372*	–0.306
Bowling shoulder angle FFC (°)	–0.052	–0.268	–0.091	–0.075	0.064	0.187
Average acceleration BFC phase (m/s ²)	–0.062	0.011	–0.050	–0.021	0.022	–0.160
Average acceleration FFC phase (m/s ²)	0.239	0.361	–0.271	–0.401*	–0.138	–0.185

*Denotes significant correlation.

Table 3. Pearson/Spearman correlation coefficients between pre-delivery stride kinematics and key performance injury-related technique characteristics.

	Jump height (normalised)	Take-off angle	Penultimate step length (normalised)	Run-up velocity (pre-jump)	Landing velocity (BFC)	Pelvic tilt (PSTO)
<i>LBSI characteristics</i>						
Front hip angle FFC (°)	-0.188	-0.159	-0.156	-0.158	0.184	0.228
Pelvic tilt FFC (°)	-0.472*	-0.449*	-0.191	0.290	0.290	0.260
Thoracolumbar rotation BFC (°)	0.050	0.318	-0.018	0.047	-0.257	-0.095
Lumbopelvic angle FFC (°)	0.316	0.352	0.352	0.130	-0.196	0.009
Rear hip angle BFC (°)	-0.098	0.247	-0.267	-0.207	0.479*	0.716*
Rear knee angle BFC (°)	-0.006	0.142	-0.220	-0.351	0.401*	0.447*
Thoracolumbar side flex BR (°)	0.074	-0.145	-0.060	-0.180	0.044	-0.183
Thoracolumbar side flex BFC (°)	-0.110	-0.203	-0.167	-0.238	0.333	0.271

*Denotes significant correlation.

COM velocity during the pre-delivery stride contact phase. This is supported by the relationships identified between pre-delivery stride vertical take-off velocity and penultimate step length with run-up velocity at BFC (Table 2). Bowlers with greater run-up speed at BFC had lower take-off trajectories at penultimate step take-off and greater penultimate step lengths. Whilst it is known that increased running speed is associated with increased stride lengths (Brughelli et al., 2011), a shorter penultimate stride length could also be related to increasing vertical take-off angle. An increase in take-off angle may be used to slow horizontal COM velocity and provide bowlers more time in the air to orientate upper and lower-limb segments ahead of the delivery stride. An optimal trade-off between run-up speed and take-off angle therefore likely exists; greater take-off angles may be indicative of bowlers looking to decelerate during the pre-delivery stride, whilst too low take-off angles may not provide the time to optimally complete the subsequent bowling action. An intervention manipulating the run-up velocity alone therefore may not be appropriate to alter take-off angle as players could run-up faster but subsequently choose to jump higher with certain bowlers requiring more time to orient themselves into position than others. Both characteristics should be considered together by coaches when working with bowlers.

Greater horizontal deceleration of the centre of mass during the FFC phase was associated with faster pre-jump run-up velocity in this study. It has previously been considered that larger front leg plant angles, and more extended front knee angles at BR, are indicative of an efficient momentum conversion strategy during this phase to convert linear momentum to angular momentum (Bhandurje et al., 2024; Kiely et al., 2021; King et al., 2016). The results of this

study, however, appear conflicting. A positive correlation between pre-jump run-up velocity and front leg plant angle at FFC, which has previously been linked to increased horizontal braking impulse during FFC (King et al., 2016), was identified. A negative correlation, however, was observed between pre-jump run-up velocity and front knee angle at BR, which has previously been linked with a more efficient transfer of linear to angular momentum during the delivery phase (Felton et al., 2023; Worthington et al., 2013). The bowlers with slower run-up velocities and lower front leg plant angles, had more extended front knees at BR. Negative correlations were also observed for penultimate step length and pre-delivery stride vertical take-off angle with front knee angle at BR, and front leg plant angle at FFC, respectively. Bowlers with greater pre-delivery vertical take-off angles and shorter pre-delivery stride lengths, were better able to achieve more extended front knee angles at BR. This may indicate a relationship exists between horizontal COM velocity and front knee kinematics during the delivery stride. It has been suggested that a bowler's optimal run-up velocity is unique to the bowler and their physical constraints (Felton et al., 2023; Felton et al., 2025; King et al., 2016). The findings of a recent study indicated bowlers may increase knee flexion with increased strength to slow down trunk flexion and increase the amount of time available to allow a greater contribution of muscular force from the upper body (Felton et al., 2025). Unfortunately, research reporting linear relationships between ball release speed and technique characteristics is often misapplied in practice with bowler's increasing their run-up speeds above their individual capabilities (Glazier & Mehdizadeh, 2019). The associations in this study may indicate that on average the bowler's run-up velocities were in excess of their individual-specific optimums. It is suggested,

therefore, that relationships between pre-delivery run-up speed, and pre-delivery take-off angle, with front leg kinematics are non-linear.

Those that landed at BFC with increased downward COM velocity displayed less thoracolumbar flexion between FFC and BR. The magnitude of thoracolumbar flexion during the delivery stride has previously been linked with ball release speed and is considered to represent the efficiency of the front leg in braking, converting the linear momentum developed in the run-up into angular momentum (Felton et al., 2023; Worthington et al., 2013). Although this could be indicative of bowlers who have jumped too high lacking forward momentum, normalised jump height was not found to be correlated with thoracolumbar flexion. Another potential explanation is that bowlers whose technique imposes demands on the lumbopelvic musculature beyond their capacity due to either pre-delivery technique or physical constraints, might flex the trunk forwards to maintain balance (Crewe et al., 2012). This could impact this relationship in two ways: (1) decreased thoracolumbar trunk flexion range between FFC and BR and (2) increased downward COM velocity.

LBSI-related effects

The strongest relationship observed between the pre-delivery stride and LBSI-related technique characteristics was observed between pelvic tilt at penultimate step take-off and the rear hip angle at BFC. Greater rear hip and knee flexion were associated with increased anterior pelvic tilt at take-off from the pre-delivery stride. The rear hip angle at BFC has previously been reported as the most important kinematic variable in predicting prospective LBSI (Alway et al., 2021). Larger anterior pelvic tilt at pre-delivery stride take-off may be indicative of inadequate lumbopelvic femoral complex control, which has been suggested to contribute to aetiology of LBSI in fast bowlers (Alway et al., 2021; Bayne et al., 2016), and/or as a result of a change in velocity (braking or change of direction) during the pre-delivery stride (Blache et al., 2011). It may also result in increased lumbopelvic extension to position the upper body upright throughout the pre-delivery phase. Repetitive lumbar extension has previously been linked in the aetiology of LBSI across multiple sports (Tawfik et al., 2020).

Greater downward landing velocity at BFC was also associated with greater rear hip and knee flexion at BFC. It has previously been suggested that bowlers may adopt more flexed rear hips and knees at BFC due to a requirement to access the increased torque available in the mid-range of the joint (Thorstensson et al., 1976) to

redirect the COM post-BFC (Alway et al., 2021). These findings support the idea by highlighting bowlers landing with greater downward whole-body COM velocity have more flexed rear leg kinematics and might as a result be predisposing themselves to greater risk of LBSI (Alway et al., 2021).

Greater anterior pelvic tilt at FFC was also found to be associated with increased pre-delivery stride take-off angles, and normalised jump heights. This may suggest that the likely greater vertical deceleration associated with the greater jump height may be beyond the capacity of the pelvis musculature to resist anterior tilting at FFC, or greater take-off angles result in a technique where flexion of the entire torso occurs earlier in the movement (being initiated by anterior pelvic tilt). It is plausible that there is a relationship between anterior pelvic tilt at FFC and lumbopelvic extension at FFC, where to maintain an extended trunk position to maximise the amount of trunk flexion between FFC and BR, lumbopelvic extension compensates for anterior pelvic tilt. Greater lumbopelvic extension at FFC is associated with increased odds of sustaining LBSI in fast bowlers (Alway et al., 2021) and may indicate a mechanism of how pre-delivery stride can directly influence kinematics associated with LBSI.

Limitations

No significant relationships were found between pre-delivery stride characteristics and ball release speed. The most likely explanation for this finding is that the movements temporally closer to ball release have greater direct influence on ball speed than those during the pre-delivery stride or unexplored variables during the pre-delivery stride might be more influential. A potential limitation of this study includes the bias within the population with all participants being male and from one nation. It is unclear whether these findings hold for differing populations of fast bowlers. Finally, the findings should be considered cautiously as multiple correlations were made without an adjustment to minimise the risk of Type 2 errors occurring (Sinclair et al., 2013) and describe the group rather than an individual. Nevertheless, this study is the first to highlight significant relationship between the pre-delivery stride and subsequent performance and injury-related technique characteristics.

Practical applications and future research

In practice, these findings will support coaching by linking the influence of the pre-delivery phase to

subsequent technique within the bowling action. Previous research on delivery stride characteristics associated with performance (Worthington et al., 2013) has widely been adopted within talent identification, development and fast bowling coaching as optimal; however, there has been limited causal understanding when attempting to intervene and alter individual technique. The results of this study demonstrate that the pre-delivery stride affects subsequent technique from both performance and injury risk perspectives. The associations identified here can inform coach development and practice. Future research should aim to understand the causes of pre-delivery stride technique to enable effective intervention, as well as explore how LBSI-related technique characteristics are influenced by medial-lateral COM velocity during the pre-delivery stride.

Conclusion

This study is the first to investigate the pre-delivery stride for elite male fast bowlers and its relationship with key performance-related and LBSI-related technique characteristics. Greater pre-delivery run-up velocity and lower take-off angles were associated with increased front leg plant angles at FFC but greater knee flexion at BR, whereas lower pre-delivery run-up velocity and greater take-off angles were associated with lower front leg plant angles but more extended front knee angles at BR. Greater anterior pelvic tilt (at PSTO), normalised jump heights, and landing velocity at BFC were associated with more flexed rear leg kinematics and greater anterior pelvic tilt at FFC. These findings suggest individual-specific pre-delivery stride run-up velocities and take-off angles exist to synchronously optimise technique to enhance performance and reduce LBSI risk. The findings of this study are likely to be useful in enhancing the coaching and LBSI-related rehabilitation of fast bowlers. Coaches and practitioners should consider the influence of the pre-delivery stride technique on subsequent fast bowling kinematics from a performance and injury risk perspective and incorporate this knowledge within their practice.

Acknowledgements

The authors acknowledge the support of Loughborough University, the England and Wales Cricket Board, and the elite bowlers who participated.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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