Anthropometric and kinematic influences on release speed in men's fast-medium bowling

PAUL S. GLAZIER,[1]* GIORGOS P. PARADISIS[2] and STEPHEN-MARK COOPER[1]

[1]*Biomechanics Laboratory, School of Sport, University of Wales Institute Cardiff, Cyncoed Campus, Cyncoed Road, Cardiff CF23 6XD and* [2]*School of Leisure and Sport Studies, Leeds Metropolitan University, Beckett Park Campus, Leeds LS6 3QS, UK*

The main aim of this study was to identify significant relationships between selected anthropometric and kinematic variables and ball release speed. Nine collegiate fast-medium bowlers (mean ± *s*: age 21.0 ± 0.9 years, body mass 77.2 ± 8.1 kg, height 1.83 ± 0.1 m) were filmed and reconstructed three-dimensionally. Ball release speeds were measured by a previously validated Speedchek™ Personal Sports Radar (Tribar Industries, Canada). Relationships between selected anthropometric variables and ball release speed and between kinematic variables and ball release speed were investigated using Pearson's product–moment correlation coefficients (*r*). A significant relationship was found between the horizontal velocity during the pre-delivery stride (*r* = 0.728, *P* < 0.05) and ball release speed (31.5 ± 1.9 m·s⁻¹). We believe that the high correlation was due to the bowlers using techniques that allowed them to contribute more of the horizontal velocity created during the run-up to ball release speed. We also found that the angular velocity (40.6 ± 3.4 rad·s⁻¹) of the right humerus had a low correlation (*r* = 0.358, *P* > 0.05) with ball release speed. Although the action of the wrist was not analysed because of an inadequate frame rate, we found high correlations between ball release speed and shoulder–wrist length (661 ± 31 mm; *r* = 0.626, *P* < 0.05) and ball release speed and total arm length (860 ± 36 mm; *r* = 0.583, *P* < 0.05). We conclude that the variance in release speed within this group may be accounted for by the difference in radial length between the axis of rotation at the glenohumeral joint and the release point.

Keywords: anthropometry, cricket, fast-medium bowling, kinematics, release speed.

Introduction

Although several factors influence the ability to bowl fast (e.g. technique, physical fitness, psychological skills, social factors), the National Cricket Association (NCA) regard technique as the most important (Stockill and Bartlett, 1992a). Recent scientific research has focused on the incidence and pathology of debilitating thoraco-lumbar spinal and intervertebral disc injuries. Although certain physiological and kinanthropometric characteristics have been suggested to relate to back injury, only biomechanical factors have been statistically linked to an increased incidence of injury.

The fast bowling action can be classified as side-on, front-on, semi-front-on or mixed depending on the orientation of the shoulder–hip axes and back foot alignment during delivery. Bowlers who use the side-on and front-on techniques are not at as much risk of injury as those who use the mixed technique. The semi-front-on action is a new technique that is based on the same principles as the two 'safe actions', where the alignment of the shoulders and hips are in the same direction. The mixed action features a realignment of the shoulders in the transverse plane during the delivery stride, which causes an increase in lumbar spine axial rotation, extension–flexion and lateral flexion. All these features occur cumulatively in a very short time when ground reaction forces are high. A combination of these factors has been linked to an increased incidence of radiological features in the thoracolumbar spine, including spondylolysis, intervertebral disc degeneration and spondylolisthesis (Foster *et al.*, 1989; Elliott *et al.*, 1992; Burnett *et al.*, 1996). Spondylolisthesis was reported in 50% of A-grade fast bowlers over a period of 5 years by Payne *et al.* (1987) and has been found to represent 45% of bony abnormalities reported by retired, elite fast bowlers (Annear *et al.*, 1992).

* Author to whom all correspondence should be addressed. e-mail: pglazier@uwic.ac.uk

Although injury will be discussed briefly later, the emphasis of this paper is on technique and optimal ball release speed. A key theoretical principle that has yet to be fully explored in fast-medium bowling, but which is integral to many overhead throwing activities, is the 'kinetic chain' (Atwater, 1979). This phenomenon is defined as a proximal-to-distal linkage system through which energy and momentum are transferred sequentially, achieving maximum magnitude in the terminal segment (Fleisig *et al.*, 1996). The acceleration of the segments with large moments of inertia facilitates eccentric contractions of the musculature surrounding the distal segments just before they contract concentrically (Joris *et al.*, 1985). Because of the work done by the proximal muscle groups, the distal muscles will contract over joints with increased strain energy, creating maximum possible forces in the distal muscles (Morris and Bartlett, 1996).

There is agreement among researchers as to the importance of ball release speed in fast bowling, but no consensus exists in the scientific literature on the elements of the bowling technique that contribute most (Bartlett *et al.*, 1996a). Additionally, no study to date has tried to quantify the influence of various anthropometric variables on ball release speed. Thus, the main aim of this study was to identify significant relationships between selected anthropometric and kinematic variables and ball release speed.

Methods

Sample

Nine collegiate fast-medium bowlers (mean ± *s*: age = 21.0 ± 0.9 years, mass = 77.2 ± 8.1 kg, height = 1.83 ± 0.1 m) from the University of Wales Institute, Cardiff (UWIC) cricket squad volunteered to participate in the study. The prerequisites for selection included the ability to release the cricket ball at a speed classified as fast (36.0–40.5 m·s⁻¹) or fast-medium (27.0–36.0 m·s⁻¹) (Abernethy, 1981). To aid logistics, all bowlers were right-handed. They had represented their top team in the British Universities Sports Association cricket tournament. Informed consent was obtained in accordance with the guidelines of the British Association of Sport and Exercise Sciences. Ethical clearance was obtained from the local ethics committee.

Experimental protocol

The participants were instructed to undertake a cricket-related warm-up activity of their choice. Each bowler was allowed an over (6 balls) of practice deliveries to aid familiarization with the test environment. An over at maximum effort was then bowled. The trial

that resulted in the greatest release speed was selected for kinematic analysis based on the assumption that movement patterns were optimized. All deliveries were bowled with a Kookaburra Turf cricket ball compliant with MCC specifications (mass of 0.156–0.163 kg and circumference of 0.224–0.229 m) at a target placed on a 'good length' (17 m). This can be defined as an area on the field where the bowler intends to pitch the ball to create indecision in the batsman whether to play forwards or back. The only items of clothing worn were training shoes and sports shorts to facilitate the identification of anatomical landmarks.

Data collection

Filming took place post-season in the UWIC sports hall on a Uniturf 6 mm synthetic rubber surface. Two gen-locked Panasonic F′15ʜs video cameras were mounted in coplanar locations, on stationary Manfrotto 117 rigid tripods, to record each delivery for digitizing purposes. Both cameras were fitted with 10 to 150 mm zoom lenses and were mounted at a height of 1.5 m, measured using a plumb-line. Each lens was adjusted to maximize the size of the performer in the viewfinder, thus enabling maximum accuracy (Winter, 1979). They were placed in the same horizontal plane and aligned so that their optical axes intersected orthogonally over the area of performance (Fig. 1). A standard PAL filming frequency was used (25 Hz) and the shutter speed was set at 1/2000 s to accommodate the rapid movements observable during delivery. Each trial was recorded with Panasonic NV-180 video recorders loaded with KONICA SUPER SG ꜱᴜᴘᴇʀ ᴠʜꜱ video cassettes.

A 25-point calibration frame (Peak Performance Technologies Inc., Englewood, CO, USA) of known world coordinates was erected approximately 20 m from each camera. As the calibration frame volume was limited to $1.9 \times 1.6 \times 2.2$ m (6.7 m³), reconstruction accuracy of real-world coordinates can only be guaranteed within the space delimited by these points (Wood and Marshall, 1986). The field of analysis was modified accordingly to encompass the period between back foot impact and the first foot contact after ball release (follow-through).

To facilitate the identification of anatomical landmarks, superficial markers were attached to the skin according to the guidelines of Plagenhoef (1971). Black electrical tape was attached around the circumference of the wrist, elbow and knee to aid location of joint centres of rotation. Where articulating structures were large in volume and subjected to large ranges of movement (e.g. glenohumeral joint and hip joints), superficial marking was avoided because it was considered instrumental in the creation of systematic error. In these cases, relevant anatomical knowledge was applied, and skin
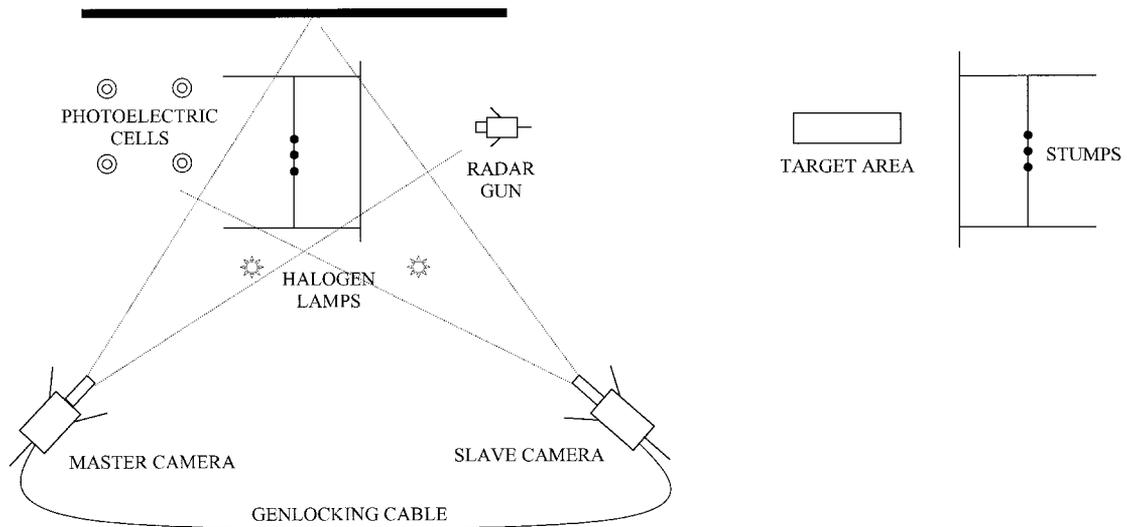
Fig. 1. Camera configuration during testing.

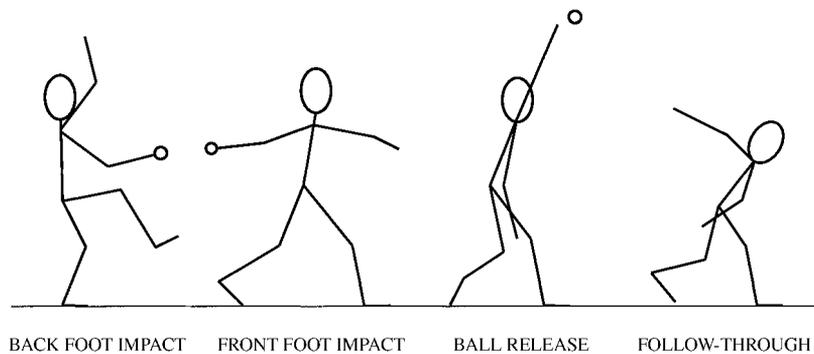BACK FOOT IMPACT   FRONT FOOT IMPACT   BALL RELEASE   FOLLOW-THROUGH

Fig. 2. Phases of delivery.

movement was considered, to accurately locate the joint centres of rotation.

To improve the clarity of the recorded image, four colour-contrasting crash mats were placed in the field of view behind the bowler. Background lighting was dimmed to reduce reflective glare, while two mains-operated Clarke™ 500 W halogen flood lamps were positioned approximately 30° forward of the plane of the picture on both the right and left sides (Plagenhoef, 1971).

Assessment of horizontal velocity of the run-up during the pre-delivery stride was achieved using two pairs of Time-It (Eleiko Sport AB, Sweden) photo-electric timing gates mounted on Miranda Tital TP20 tripods. The first pair was situated 0.5 m back from the point of back foot placement for the pre-delivery stride, thus producing no interference with the recorded image. Another pair was placed 1.5 m further back on the run-up. Times were displayed by the receiver head, which allowed speed derivatives to be calculated. Care was taken to ensure that the infrared beam was not broken prematurely by distal limbs by setting the lights at a height approximately level with the bitrochantic line of each bowler.

Data reduction

A Windows®-based Peak Motus™ Motion Measurement System (Version 3.0, Peak Performance Technologies Inc., Englewood, CO, USA) software package was used to reduce data from film. An interfaced Panasonic AG-6500 video playback system increased the sampling rate to 50 fields per second. A user-defined 18-point, 16-segment spatial model was selected and points 1–18 were digitized between back foot impact and the follow-through. Ten additional fields were digitized before back foot impact and 10 fields after follow-through for smoothing purposes.

The transformation of two-dimensional image coordinates to three-dimensional world coordinates was achieved using a direct linear transformation (DLT) algorithm with correction for symmetrical lens

distortion (Karara and Abdel-Aziz, 1974). Centre of mass calculations were based on the cadaver data of Dempster (1955), adjusted by Miller and Nelson (1973) to account for fluid and tissue losses. As the model employed was user-defined and had only 12 segments (no hand segments), the relative body segment masses were modified further.

Gaussian noise was removed from the digitized data using a cubic spline algorithm. The amount of conditioning for each curve in each dimension was calculated by the software using the Jackson Knee Method (Jackson, 1979). Having calculated the residual difference between raw data and filtered data, a curve was calculated with each filter parameter along the horizontal axis and the percent average residual at each filter parameter along the vertical axis. Finally, the second derivative of this curve was found at each filter parameter. Starting at a filter parameter of zero and working across the horizontal axis to the right, groups of three were sampled consecutively until a group of three second derivatives fell beneath a defined prescribed limit. This was identified as the 'knee point'. The smallest filter parameter in this group was considered optimal.

Ball speed measurement

As the field of view was limited, a Speedchek™ Personal Sports Radar Gun (Tribar Industries, Canada), which has previously been verified as valid (Glazier *et al.*, 1999), was used to measure ball release speed. The radar unit was placed approximately 7 m from the point of delivery, in line with the stumps and pointing towards the bowler. In an attempt to negate extraneous influences (e.g. limb velocity), the PRO-MODE function was selected to reject any speeds below $16 \text{ m} \cdot \text{s}^{-1}$.

Anthropometric measurements

Height, total body mass and anthropometric lengths (shoulder–elbow, elbow–wrist and hand lengths) of the bowling arm were assessed using the standardized guidelines provided by Martin *et al.* (1988) and Ross and Marfell-Jones (1991). Items of clothing that interfered with the measurement process were removed before testing to maximize accuracy. All measurements were taken with an anthropometer configured as a sliding-beam calliper. Intra-rater reliability measurements were taken at approximately the same time of day with an intervening time interval of 48 h.

Statistical analysis

All summary statistics are presented as the mean ± standard deviation (*s*) unless otherwise stated. Normal distribution was verified by Anderson-Darling normality plots implemented in MINITAB (Minitab Inc., 1995). Directionalized alternative hypotheses (H_1: $r > 0$) were postulated between bowling humerus angular velocity and ball release speed and between anthropometric lengths and ball release speed in view of the logical relationship between these variables. Otherwise, null hypotheses (H_0: $r = 0$) were postulated between the remaining independent variables and ball release speed. Pearson's product–moment correlation coefficients (*r*) were used to identify significant relationships (d.f. = 7, $P < 0.05$, $r_{\text{crit}} = 0.582$ one-tailed, 0.666 two-tailed) between selected kinematic and anthropometric variables and ball release speed. The 95% level of confidence ($\alpha = 0.05$) was set *a priori*. Coefficients of determination (r^2) were used to identify the meaningfulness of *r*. This is a measure of the amount of variance the two variables share (Munro, 1997). Power analysis was also used to identify the probability of correctly rejecting a false H_0. Ninety-five percent limits of agreement (equation 1; Bland and Altman, 1986) were used to evaluate absolute errors in the anthropometric data as well as digitizer precision:

$$\text{boundaries of agreement} = \delta \pm 1.96\sigma \qquad (1)$$

where δ = the mean of the differences between data sets and σ = the standard deviation of differences between data sets.

Results and discussion

Validation of methodological tools

With respect to the estimation of intra-rater reliability, the differences between repeated applications of all anthropometric variables were normally distributed ($P = 0.29$) and the systematic bias and boundaries of agreement were calculated to be 0.15 ± 2.2 mm. This suggests that the maximum random error component was approximately 2.2 mm ($P < 0.05$). Although objective criteria for interpreting the meaningfulness of the error interval were not available, we consider that the limits of agreement are narrow enough for the measurements to be deemed valid (Atkinson and Nevill, 1998). Thus, we suggest that the small amount of random error present in the anthropometric data had a negligible effect on the subsequent statistical outcomes.

The differences between the repeated measurements for right elbow displacement were found to be normally distributed ($P = 0.09$). Systematic bias and the boundaries of agreement were calculated to be 0.01 ± 0.049 m. The maximum random error component was approximately 0.059 m. Objectivity was assessed using two sets of displacement coordinates for

the left hip that had been derived from coordinate data created by the main digitizer and one other experienced operator. The differences between the data sets failed normality ($P = 0.01$), thus the boundaries were adjusted to $\delta \pm 2\sigma$ (Bland and Altman, 1986). Systematic bias and the boundaries of agreement were calculated to be 0.018 ± 0.046 m. The maximum random error component was approximately 0.064 m. Considering the relatively large field of performance as well as the rapidity of the action, these random errors were deemed satisfactory.

Technique classification

The main aim of this study was to identify the anthropometric and kinematic variables that contribute to ball release speed. The mean ball release speed was found to be 31.5 ± 1.9 m·s^{-1}, which is considerably slower than that reported by Stockill and Bartlett (1992b) for a group of 17 Test and county fast bowlers (37.4 ±

1.9 m·s^{-1}), but comparable to a group of 20 elite representatives (31.7 ± 1.6 m·s^{-1}) measured by Elliott *et al.* (1992).

Table 1 provides the type of action used by the bowlers based on the classification systems of Foster *et al.* (1989) and Elliott *et al.* (1992). The former classified the mixed action as having a counter-rotation of more than 40°, whereas the latter suggested that even a 10° reduction in shoulder alignment between back foot impact and front foot impact may predispose to injury. For this reason, the classification system of Elliott *et al.* (1992) was used to define the bowling techniques used in this study.

Considering some of the large angles ($28 \pm 14°$) of counter-rotation reported in Table 2, the incidence of back injury within the group was small (only bowler #4 reported a history of back injury). It is possible that the bowlers in this study have not experienced the volume of match-play and practice as those bowlers in previous studies (Foster *et al.*, 1989; Elliott *et al.*, 1992). Furthermore, the younger participants in the study of Foster *et al.* (1989) might have been underdeveloped, making them prone to overuse injuries (Payne *et al.*, 1987). Musculoskeletal structures that have yet to reach full maturity are unlikely to effectively attenuate peak vertical ground reaction forces approximating 3.8–6.4 times body mass (Bartlett *et al.*, 1996a), especially if a faulty technique is used or if the bowler is fatigued.

Stockill and Bartlett (1992b) have suggested that presenting counter-rotation values in absolute terms may be misleading because the hips may rotate at the same rate as the shoulders, thus reducing the counter-rotation. Those authors suggested that future studies should present the shoulder alignment in relation to hip alignment (shoulder–hip separation angles), as depicted in Fig. 3.

Table 1. Classification of technique

| Bowler | Type of action | |
	Foster *et al.* (1989)	Elliott *et al.* (1992)
1	Mixed	Mixed
2	Front-on	Mixed
3	Front-on	Mixed
4	Front-on	Mixed
5	Front-on	Mixed
6	Side-on	Side-on
7	Front-on	Mixed
8	Front-on	Mixed
9	Mixed	Mixed

Table 2. Shoulder alignments and back foot angles during the delivery stride

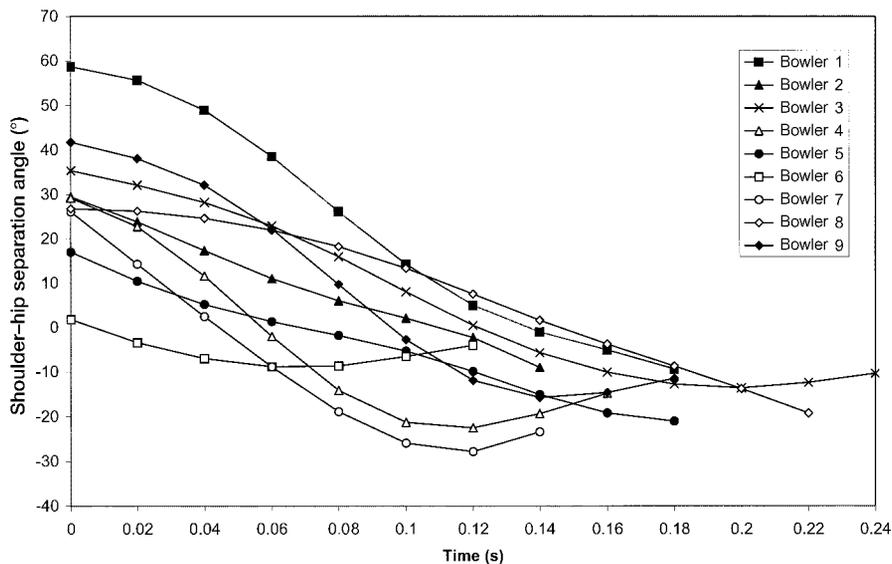| Bowler	Back foot impact (°)	Front foot contact (°)	Minimum (°)	Back foot angle at back foot impact (°)	Maximum counter-rotation (°)
1	239	197	191	269	48
2	216	208	196	279	20
3	223	205	184	301	39
4	218	204	193	291	25
5	200	210	179	273	21
6	186	196	177	273	9
7	212	209	190	278	22
8	210	206	190	299	20
9	229	194	181	281	48
Mean	215	203	187	283	28
s	16	6	7	12	14

Fig. 3. Plots of individual shoulder–hip separation angles with respect to time from back foot impact to front foot impact.

One factor that may predispose fast bowlers to injury is the hip–shoulder separation angular velocity represented by the gradient of each line. A large change in angular displacement over a short time is likely to create large torsional loads in the lumbar region of the vertebral column, especially when under compressive loading. Considering the large moment of inertia of the upper torso and pelvis, high inter-segment torques are likely, which may overload the annulus fibrosus, resulting in peripheral annular bulging and development of other radiological features.

Owing to the very specific classification boundaries, precise methods of determination are required to accurately ascertain shoulder and hip orientations. Stockill and Bartlett (1996) highlighted some of the problems associated with determining hip and shoulder alignments when both optical axes are in the same horizontal plane. Previous studies have used overhead cameras (Elliott and Foster, 1984; Foster *et al.*, 1989; Elliott *et al.*, 1992) and multiple camera configurations (Burnett *et al.*, 1995) to accurately determine align-

ments. Because of the limitations of this study, these methods could not be used but similar procedures are advocated in future research.

Kinematics during delivery

Relationships between selected anthropometric and kinematic parameters were investigated using Pearson's product–moment correlation coefficients (see Table 3). There was evidence of a strong relationship between the horizontal velocity of the run-up during the pre-delivery stride (5.9 ± 0.7 m·s^{-1}; $r = 0.728$, $P < 0.05$, $r^2 = 53.0\%$) and ball release speed. Previous research has suggested that bowlers using a front-on technique are able to approach faster and contribute more of the horizontal velocity created during the run-up to the speed of ball release than side-on bowlers, who have to change orientation during the pre-delivery stride (Elliott and Foster, 1984; Bartlett, 1992). As the mixed technique has a front-on orientation at back foot impact, this may account for the high correlation observed.

Table 3. Pearson's product–moment correlation coefficients (*r*) between ball release speed and selected anthropometric and kinematic variables (95% confidence intervals are also provided for statistically significant results)

Variable	*r*	*P*	95% CI
Run-up speed at pre-delivery stride	0.728	0.026**	0.130 to 1.73
Angular velocity of the bowling humerus	0.358	0.172	N.S.
Angle of the front knee at front foot impact	−0.190	0.624	N.S.
Shoulder–wrist length	0.626	0.036*	−0.065 to 0.910
Total arm length	0.583	0.050*	−0.130 to 0.900

* r_7 (0.05) = 0.582 (one-tailed test); ** r_7 (0.05) = 0.666 (two-tailed test).

Based on the initial horizontal velocity created by the run-up, there is evidence of a sequentially timed coordination of the speeds of the right hip (5.6 ± 0.6 m·s^{-1}), seventh cervical vertebra (6.3 ± 0.5 m·s^{-1}), right shoulder (7.4 ± 0.6 m·s^{-1}), right elbow (15.4 ± 1.6 m·s^{-1}) and right wrist (27.0 ± 2.7 m·s^{-1}) (Fig. 4). Although the sequencing of segmental accelerations is important, it is unlikely to be the reason for lower ball speeds. In a study by Bartlett *et al.* (1996b) to identify the differences in javelin release parameters among individuals of varying skill, even novice javelin throwers (mean distance 29.80 m) had a correct pattern of temporal sequencing. Therefore, it is logical to assume that differences lie in the speed of each joint centre, with elite bowlers attaining greater speeds at each joint.

Previous studies have tried to evaluate the relative contributions of the run-up, leg action and hip rotation, trunk flexion and shoulder girdle rotation, arm action and hand action to ball release speed. Davis and Blanksby (1976) applied restraints to isolate certain limbs, but this has been criticized for assuming that the actions of these body segments are unaffected by the actions of more proximal and distal segments and hence that each segment relies on muscular activity alone (Burden, 1990).

A more suitable alternative is to subtract the peak linear speed of the preceding proximal landmark from the subsequent distal landmark in the link system and then express this as a percentage of ball release speed. Using this procedure, we found that hip action contributed 1.6%, trunk action 5.7% and arm action 62.2% of ball release speed. By subtracting the run-up speed at back foot impact from ball release speed, we found that

the run-up contributed 16.2%. Although hand and finger action were not analysed because of an insufficient frame rate, they were estimated by subtracting the peak linear velocity of the right wrist from the ball release speed and then expressing this as a percentage of the ball release speed. Using this method, we calculated that hand and finger action contribute 14.3% to ball release speed.

Anthropometric influence

Stockill and Bartlett (1994) suggested that senior international fast bowlers attain greater ball release speeds than their junior international counterparts because of a combination of slightly higher angular velocities of the bowling humerus and longer upper limb lengths. In this group of bowlers, angular velocity of the bowling humerus (40.6 ± 3.4 rad·s^{-1}) had a poor relationship with ball release speed (31.5 ± 1.9 m·s^{-1}, $r = 0.358$, $P > 0.05$). Although the action of the wrist was not analysed, high correlations between ball release speed and shoulder–wrist length (661 ± 31 mm; $r = 0.626$, $P < 0.05$) and ball release speed and total arm length (860 ± 36 mm; $r = 0.583$, $P < 0.05$) suggested that the dominant factor – in a sample that was homogeneous in terms of ball release speed – was the radial length. The shared variance between shoulder–wrist length and ball release speed and total arm length and ball release speed was 39.2% and 34.0% respectively. It is interesting to note that 60.8% and 66.0% of the variance, respectively, was not accounted for by these variables, but by other components of the bowling action. Statistical power for the r-values was 62.1% and
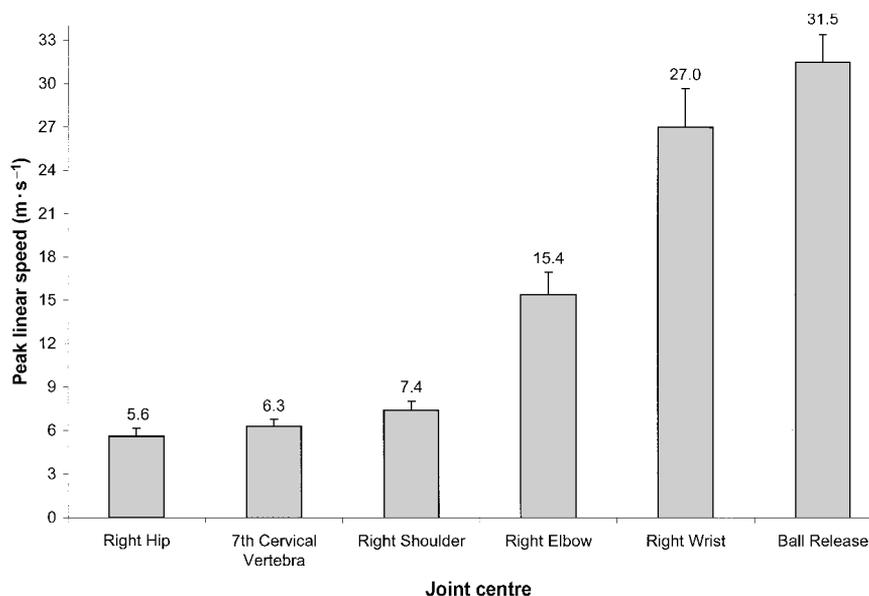

Fig. 4. A graphical depiction of the proximal-to-distal summation of linear speed (mean $\pm$ *s*).

49.0% for shoulder–wrist length and ball release speed and total arm length and ball release speed respectively, which has been described as a relatively large effect (Cohen, 1988).

As the bowling arm is essentially a quasi-rigid body as governed by the laws of cricket, the peak linear speed of the wrist is proportional to the length of the radius for any given angular velocity. At the angular velocity reported in this study, an increase in the radial length of 0.1 m at the segment endpoint equates to an increase in speed of approximately 3.3 m·s⁻¹. By maximizing the linear speed at this location, a more efficient proximal-to-distal transfer of angular velocity between segments is probable, providing that correct temporal patterning occurs. We hypothesized that, providing the impulse vector is directed through the ball's centre of mass, ball release speed will be increased.

It is reasonable to hypothesize that anthropometric variation may in part be the differentiating factor between elite international fast (36.0–40.5 m·s⁻¹) and express (>40.5 m·s⁻¹) bowlers. Such anthropometric differences are readily apparent in fast bowlers of Afro-Caribbean origin, who tend to have an ectomorphic physique. Furthermore, it has been suggested that Black males have a greater percentage of type II muscle fibres, together with superior phosphagenic and glycolytic metabolic pathways (Ama *et al.*, 1986), making them ideally suited to the high-intensity activity of fast bowling (Hook, 1990). These anthropometric and morphological variations, combined with various social factors, could explain why the West Indies has a history of producing world-class fast bowlers.

Conclusion

The main aim of the present study was to identify significant relationships between selected anthropometric and kinematic variables and ball release speed in men's fast-medium bowling. A proximal-to-distal kinetic chain was identified in all bowlers. A sequential increase in peak linear speed was identified in the right hip, seventh cervical vertebra, right glenohumeral joint, right elbow and right wrist linkage system. Although the action of the run-up, hip and trunk is important, greater variance in peak linear speed was noted in the more distal landmarks of the kinetic chain. We suggest that the smaller inertial parameters, combined with a greater radial length, was the main reason for this.

Acknowledgements

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