MECHANICS OF REAR LEG MOTION IN CRICKET FAST BOWLING

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The purpose of this study was to calculate the kinematics and kinetics of the rear leg drive in fast bowling, and then investigate whether any of these variables are associated ball release speed. Eighteen young fast bowlers (17.2 ±1.7 years) were recruited from the Cricket NSW development squad, and their bowling actions captured by a Cortex 2.0 motion analysis system. The data shows that rear leg drive primarily consisted of hip and knee motions in the flexion-extension plane, subject to a complex control strategy involving time-varying torques. The most prominent kinematic feature was rear knee extension velocity (r=0.55, p=0.019), which was moderately correlated with ball speed. However, more research is needed to evaluate the control of this variable, since none of the rear leg joint torques was correlated with rear knee extension velocity.

KEY WORDS: kinetics, kinematics, cricket, bowling.

INTRODUCTION: It is well accepted that fast bowlers play a key role in determining a cricket team's success. By releasing the ball at high velocities of up to 45 m s^{-1}, batsmen are given only a short time in which to perceive and react to the ball, increasing their chance of dismissal. To produce such fast ball speeds, it would be beneficial if the body segments were coordinated in a mechanically efficient sequence, making the production of ball speed easier and less likely to cause injury. A proximal to distal sequencing of body segments has been associated with high end-effector speeds in other athletic motions, such as the tennis serve and baseball pitching, and has also been identified as a feature in fast bowling. For instance, in bowling, the pelvis rotates prior to the shoulders resulting in a pelvis-shoulder separation angle that has been moderately correlated with ball speed (Portus, Mason, Elliott, Pfitzner & Done, 2004). However, there is very little understanding on the influence of the rear lower limb on the segmental sequencing of the bowling action, and its consequential effects, if any, on ball release speed.

Although the term 'rear leg drive' is commonly used as a coaching concept, it has seldom been scientifically investigated in sports. In the tennis serve, Reid, Elliott & Alderson (2007) defined rear leg drive as occurring from maximum rear knee flexion to maximum external rotation of the serving arm, describing a period in which the humeral internal rotators of the serving arm are pre-stretching, such a pre-stretching phase of the arm musculature usually requiring the assistance of inertial lag, a property that is generally induced on the hitting arm only after a phase of rapid pelvic rotation. Hence, it makes sense to consider maximum rear pelvic rotation velocity as a major kinematic characteristic of the rear leg drive, something that has been supported by previous research in the tennis forehand and baseball batting, knee extension of the rear leg found to correspond with the time when pelvis rotation velocity is increasing in both these hitting motions (Welch, Banks, Cook, & Draovitch, 1995).

If it is accepted that a well-performed leg drive in fast bowling initiates pelvic rotation, then it could feasibly also influence the pelvic-shoulder separation angle, suggesting a means by which leg drive can influence ball speed. However, there is more to consider in the analysis of leg drive than merely knee extension kinematics. The rear thigh can also rotate about the hip joint in the adduction-abduction and flexion-extension planes, motions that also 'drive' the rear leg forwards. Furthermore, the calculations of hip and knee joint torques approximate the net muscle dynamics used to actuate and control the motion of the rear leg. This information may be more important to coaches and bowlers than just a descriptive account of kinematics. Hence, the aim of this study was to calculate the three-dimensional kinematic and kinetic characteristics of the rear leg in a sample of elite young bowlers, firstly to provide a descriptive account of rear leg drive, and secondly to investigate whether the performance rear leg drive is associated with ball speed. The hypothesis of this study is that kinetic and kinematic variables relating to rear leg drive are associated with pelvis rotation velocity and ball speed.

METHODS: Eighteen young fast bowlers (17.2 ±1.7 years) were recruited from the Cricket New South Wales development squad. The trials were performed in a biomechanics laboratory, which permitted a full length run-up. A 14-camera Cortex Motion Analysis System (Version 1.0, Motion Analysis Corporation Ltd., USA) captured the three-dimensional (3D) motion (200 Hz) and force plate (1000 Hz) data of 20 trials for each bowler, including both the front and rear foot contacts made separately on each of two Kistler force plates. Each subject was instructed to bowl at maximum effort as in match conditions. Five trials in which the ball landed within a 'good length' area, demarcated by two white lines 13 m and 19 m from the stumps at the bowler's end, were selected for analysis. Subjects also rated their performance from 0 to 10 using an analogue performance scale. The video capture volume encompassed the back foot contact, front foot contact, ball release and follow through phases of the bowling action. The Cortex system was calibrated according to the manufacturer's recommendations resulting in a residual error of marker position of less than 1 mm.

Motion analysis capture was performed on each subject wearing a full body marker set comprising fifty-one 15 mm spherical markers, which were attached to bony landmarks (Ferdinands, 2010). Markers were located on the left and right sides of the body except for markers placed half-way between the posterior superior iliac spines (mid-PSIS), and on the 7th cervical vertebrae, supra-sternal notch, and the head. The positions of the anterior superior iliac spine (ASIS), mid-PSIS, and greater trochanter markers were used to calculate the hip joint centres. All other joint centres were calculated as the average position between two markers placed either medially and laterally or anteriorly and posteriorly on the joint. Exceptions were the position of the shoulder, mid-trunk, hip markers, and cricket ball. A recursive fourth-order low-pass Butterworth filter was used to smooth the motion analysis data. The cut-off frequencies (8 – 15 Hz) were determined from residual analyses.

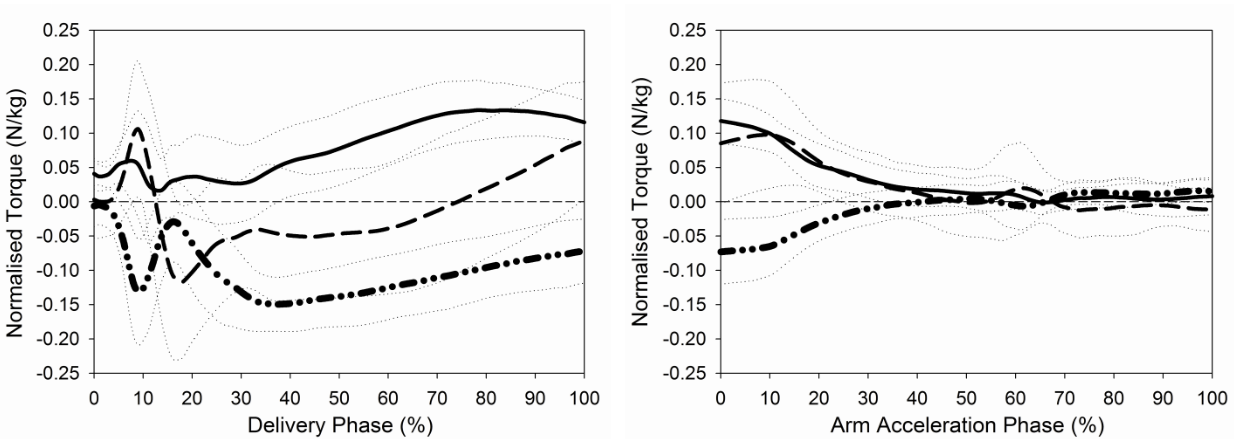
The three-dimensional motion analysis data of the markers were imported into a four-segment rigid body kinematics and kinetics model of the rear leg designed in Kintrak (V.7.0, University of Calgary), a software programme that performs kinematics and inverse dynamics analysis using motion analysis and force plate data. Local segment coordinate systems of the rigid body model were defined for the pelvis and rear leg, based on the methodology of Grood and Suntay (1983): the adduction-abduction axis calculated as the cross-product of the long-axis vector and the vector from a distal lateral joint marker to the proximal joint centre; the flexion-extension axis calculated as the cross product between the long axis vector and the adduction-abduction axis vector.

Angular velocities and torques were calculated about the adduction-abduction and flexion-extension axes of their respective joint coordinate systems over two phases of the bowling action: the delivery stride phase, defined from back foot contact to front foot contact; and the acceleration phase, defined from front foot contact to ball release. Net joint torques were calculated about the proximal ends of the thigh and shank segments, (i.e. calculated about the hip and knee joints, respectively). Rotational directions corresponding to adduction and flexion were defined as positive. Pearson's correlation coefficients were calculated in SPSS (Version 17, SPSS Inc.) to assess the relationship between ball speed and segment angular velocity and torque variables, based on maxima, minima, mean and RMS values.

RESULTS: The rear leg exhibited a common movement pattern during the delivery stride phase, having a relatively small hip velocity in the adduction-abduction plane (RMS, 1.8 ±0.7 $rad.s^{-1}$) compared to both hip extension velocity (RMS, 4.4 ±1.3 $rad.s^{-1}$) and knee angular velocity in the flexion-extension plane (RMS, 5.5 ±1.4 $rad.s^{-1}$). The knee flexed for a little more than half of the delivery phase (0–62%) before extending at an increasing rate for the remainder of the phase.

There was a change in general rear leg movement pattern during the arm acceleration phase, the hip now rotating with a component of abduction angular velocity (RMS, 3.4 ±1.2 $rad.s^{-1}$) for the entire phase and a component of flexion angular velocity (RMS, 6.0 ±1.5

rad.s^{-1}) for 29 – 100% of the phase. The magnitude of knee angular velocity (RMS, 4.9 ±1.4 rad.s^{-1}) was similar to that during the delivery phase, except that extension occurred during the first half of the phase (0–51%), before being followed by flexion for the remainder of the phase.
Figures 1a & 1b show the hip and knee joint torque components that during the delivery stride and arm acceleration phases, respectively.



Figures 1a (left) and 1b (right): Ensemble averages (±SD) of rear leg joint torques normalised with respect to body weight x height. Rear hip flexion-extension torque (solid line), rear hip adduction-abduction torque (plain dash) and rear knee flexion-extension torque (dash-double dot) calculated over the delivery phase (left) and arm acceleration phase (right). Flexion and adduction were defined as positive.

There were no significant correlations between rear leg kinetics variables (the variables comprising the mean and peak joint torques and powers) and ball speed ($p > 0.05$). There was only one significant kinematic correlation with ball speed, that of the maximum rear knee extension velocity during the delivery phase ($r=0.52$, $p=0.029$). The maximum rear knee extension velocities during the delivery phase and the acceleration phase were also correlated with the RMS pelvic rotation velocity during the arm acceleration phase, both having $r=0.55$ with $p = 0.019$. The RMS pelvic rotation velocity during the arm acceleration was in turn correlated with mean ball speed ($r=0.52$, $p=0.029$). There were also no significant correlations between rear leg kinetics variables and rear knee leg extension velocity.

DISCUSSION: The purpose of this study was to provide a descriptive account of rear leg drive in terms of kinetics and kinematics, and investigate how rear leg drive influences bowling performance. The hypothesis was that rear leg drive influences pelvic rotation and is correlated with ball release speed.
The kinematic data showed that rear leg action in bowling primarily consisted of hip and knee motions in the flexion-extension plane, each motion initiated at a specific time in the phase and lasting for a particular duration. Rear knee extension did not begin immediately upon back foot contact. Prior to 62% of the delivery phase, the rear hip was extending while the knee was flexing, both motions the natural consequence of having to absorb the large vertical and braking ground reaction forces during this time, a property that has been documented in many previous studies. Only after 62% of the delivery phase did the rear knee begin extending, clearly becoming the most rapid of all the rear leg movements, and continuing its extension until the end of the first half of the acceleration phase. It is important to note that for much of the period when the knee was extending, the hip was also extending: from the moment the knee began its extension to 29% of the arm acceleration phase. From 29–51% of the arm acceleration phase, the knee was extending but the hip was now flexing. From 51% to the end of the acceleration phase, both the knee and hip were flexing. There was also movement of the hip in the adduction-abduction plane: a small hip adduction velocity registered in the delivery phase, a higher hip adduction velocity registered in the acceleration phase, but both values considerably lower than the flexion-extension velocities.

The flexion-extension torques are relatively simple to follow (Figure 1a & 1b). Hip flexion torque and knee extension torque occurred simultaneously, their magnitudes maintaining a relatively steady value, except for some small early fluctuations, before decreasing almost linearly to zero by the middle of the arm acceleration phase. However, the overall control of the rear leg segments was more complex: the knee extension torque acting to control the rate of knee flexion from 0–62% of the delivery phase, before acting in the direction of knee extension from this point onwards until its magnitude became virtually zero at 50% of the arm acceleration phase; the hip flexion torque acting to control the rate of hip extension from the time of back foot contact until 29% of the arm acceleration phase, before acting in the direction of hip flexion. Similarly, the hip adduction-abduction torques acted either in the same or opposite direction to the hip angular velocity in the adduction-abduction plane, generally acting in the direction of hip adduction velocity in the delivery phase, and controlling the rate of hip abduction velocity in the arm-acceleration phase.
In terms of determining the influence of rear leg action on ball release speed, only the rear knee extension velocity was found as a potential factor, the maximum rear knee angular velocity in both phases being moderately correlated with ball speed (r=0.55). A possible mechanism of influence may be via pelvic rotation velocity, since the maximum rear angular velocity during the delivery phase was moderately correlated with the RMS pelvic rotation velocity during the arm acceleration phase, which was in turn moderately correlated with the mean ball speed (r=0.52). However, the causal mechanism underlying rear knee extension velocity was not identified, since there was no significant correlation between rear knee extension torque and rear knee extension velocity.

CONCLUSION: In this study, the rear leg mechanics in fast bowling was investigated with the objective of increasing the current level of understanding on this aspect of technique, providing bowlers with information on how to improve their rear leg motion, and potentially increasing their ball release speed. The data showed that rear leg action comprised a number of simultaneous motions, subject to a complex control strategy involving time-varying torques, the process far more complicated than previously conceptualised. Supporting one hypothesis of this study, rear knee extension velocity was correlated with pelvic rotation velocity, a finding consistent with the notion that rear leg drive promotes pelvic rotation. However, in terms of finding elements of rear leg action that may increase ball speed, rear knee extension velocity was moderately correlated with ball speed, but more research is needed to determine how rear knee extension velocity can be increased, since none of the rear leg joint torques was correlated with this variable, suggesting that its control involves the coordination of other body segments, perhaps those even located remotely from the legs.

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