A Three-Dimensional Cinematographic Analysis of the Fastball and Curveball Pitches in Baseball

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Three-dimensional (3-D) high speed photography was used to record the fastball (FB) and curveball (CB) actions of six members of the Australian National pitching squad. The direct linear transformation (DLT) method of motion analysis for 3-D space reconstruction from 2-D images was used to record the movement of selected anatomical features. Laterally positioned phase-locked cameras operating at 200 fps and a front-on camera operating at 300 fps were used to record the pitching action. Mean pitching velocities for the FB and the CB were recorded. A kinematic analysis of the two pitching motions from the first balance point following the completion of the pump and pivot to follow through are presented. The actions are very similar for the two pitches, as would be expected if disguised to confuse the batter. Minor differences were noted, however, for stride length, forearm action prior to release, and wrist action at release.

Baseball is a team game in which success is determined by overall strength in batting, pitching, and fielding. The defensive nature of the game causes it to be dominated by the skill of the pitcher. The pitcher therefore, either through

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Correct pitching mechanics in throwing the fastball (FB) and curveball (CB) would assist a pitcher to develop command and control of ball velocity, accuracy, and flight pattern. Three-dimensional high speed photography was used in this study to record the FB and CB actions of elite Australian pitchers. An analysis of the mechanisms was then performed in an attempt to clearly identify both the similarities and differences in pitching techniques for these two pitches.

**Methods and Procedures**

**Sample**

Six male members of the Australian baseball pitching squad, mean age 25 years, were used as subjects. On arrival the subjects were painted at appropriate anatomical landmarks by two trained testers (the tip of the middle finger was used to indicate the distal end of the hand). Subjects were then permitted as much time as needed prior to the filming to complete their warm-up procedures. A practice pitching mound was available for all preliminary pitching warm-ups. On completion of this preparation, each pitcher observed the following pitching sequence from a fiberglass and rubber mound positioned in an indoor laboratory.

1. Eight practice pitches (fastball).
2. Two fastballs from a wind-up.
3. Five practice pitches (curveball).
4. Two curveballs from a wind-up.

Sections 2 and 4 were continued until an umpire positioned behind the catcher was satisfied that two strikes had been thrown by the pitcher.

**Administration and Filming Procedures**

Filming was conducted at an indoor biomechanics laboratory with the pitchers throwing over a distance of 18.44 meters at a pitching grid which indicated the strike zone with a catcher behind the plate. (The grid and catcher were positioned in front of camera B, Figure 1). The direct linear transformation (DLT) method of motion analyses for 3-D space reconstruction from 2-D images was used. This procedure involved an initial filming by two Photosonics phase-locked cameras of a reference structure containing markers of known coordinates in space which encompassed the field of movement of the pitching action (Wood & Marshall, 1985). This structure was then removed and the subject was filmed dressed only in shorts and pitching shoes in the same object space with the same camera positions. Both phase-locked cameras operating at 200 fps were positioned with a subject distance: camera base ratio of 2:1 as recommended by Wood and Marshall (1985—Figure 1). A third Photosonics camera operating at 300 fps was positioned in line with the direction of the pitch (Camera B, Figure 1).

A conical shaped clock that completed a full rotation every 1 second was used for the calibration of filming speed. Kodak color negative (7294) 320 ASA
tungsten rated film was used in all cameras. In all, 25,000 kilowatts of artificial light were required to permit filming by the phase-locked cameras at 200 fps with a 30-degree variable shutter angle (exposure time = 1/2400th s). The front-on camera set at 300 fps with a 45-degree variable shutter angle also had an exposure time of 1/2400th of a second.

**Analysis and Treatment of Data**

After processing, one trial for each pitcher for both a FB and CB was selected for analysis. The criteria used to select this trial were that the higher velocity pitch of the strike pitches was chosen for the FB and the better break from the two successful pitches was chosen to represent the CB.

The film image of each throw was projected by a NAC 16 mm motion analysis projector, via a 45-degree mirror onto the horizontal surface of the analysis table (scale multiplier for image to real size conversion, 9.5:1). The 2-D images of both the reference structure (13 points) and subject were then digitized, and the unknown 3-D coordinates of each of the subject's landmarks were determined using the procedures outlined in Marzan and Karara (1975) and Wood and Marshall (1985). After digitizing, the data were then transferred to a disc storage area of the DEC System-10 computer. Three-dimensional joint angles and angular velocities were then calculated. A 2-D file was also created so that coordinates from the sagittal plane could be used to calculate segment lengths, linear and angular displacements, and velocities using procedures outlined by Wood (1977). An automatic low pass digital filtering procedure (similar to the
technique developed by Wells & Winter, 1980) developed by Wood and Marshall (University of Western Australia) was used so that different anatomical landmarks and body segments could be smoothed at different frequencies.

Results and Discussion

Studies comparing and contrasting pitching velocities have indicated that the CB is significantly slower than the FB (Atwater, 1977; Hay, 1978). In this study the mean velocity immediately after release for the FB was 35.1 m.s\(^{-1}\) (78.6 mph—Table 1) and the mean velocity of the CB was 28.2 m.s\(^{-1}\) (63.1 mph—Table 1). These differences in velocities correspond almost exactly to the 15 mph difference observed by Litwhiler (1979) for the FB and CB. The velocities are comparatively slower than those cited by Hay (1978) in studies comparing college and professional pitchers. However, the fact that the velocities in this study were recorded under laboratory conditions may account for some of this difference.

Comparison of the FB and CB actions began at the first balance point following completion of the windup and pivot. The stance, windup, and pivot phases of the pitching action, however, are important preparatory movements that must be carefully executed if the ball is to be thrown with velocity and control.

Similar techniques were observed for both the FB and CB during the movement to the first balance position. Shaw (1972), Watts (1973), and Polk

<table>
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<tr>
<th>Table 1</th>
<th>Kinematics of the FB and CB Pitching Actions (n = 6)</th>
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<tbody>
<tr>
<td></td>
<td><strong>FB</strong></td>
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<tr>
<td>Height of lead knee above the hip during pivot (cm)</td>
<td>33.1</td>
</tr>
<tr>
<td>Angle of thigh past 90° pivot (°)</td>
<td>27.0</td>
</tr>
<tr>
<td>Angle of leg (°) past vertical</td>
<td>16.5</td>
</tr>
<tr>
<td>Hand break (above the hip) (cm)</td>
<td>17.4</td>
</tr>
<tr>
<td>Stride length (cm)</td>
<td>154.2</td>
</tr>
<tr>
<td>Stride length/height (%)</td>
<td>82.3</td>
</tr>
<tr>
<td>Stride alignment (cm) ±</td>
<td>7.0</td>
</tr>
<tr>
<td>3-D Elbow angle at release (°)</td>
<td>144</td>
</tr>
<tr>
<td>Ball velocity m.s(^{-1})</td>
<td>35.1</td>
</tr>
</tbody>
</table>
(1982) suggested that the "non-pivot" or stride limb should be lifted during the pivot so that the thigh is parallel to the ground and the leg and foot hang straight down at the first balance position. The Australian pitchers tended to swing the limb off the ground for both the FB and CB during the pivot, causing the thigh to be rotated past a vertical line drawn through the hip joint (FB—27°; CB—24.6°), the leg to be swung past a vertical through the knee joint (FB—16.5°; CB—16.8°), and the thigh to be elevated higher than the horizontal (FB—33.1 cm; CB—32.7 cm: Table 1).

The break of the hands occurred 17.4 cm above the hips for the FB and 18 cm above the hips for the CB. Although there was considerable variability in the position of the break of the hands for both pitches, the area of the break was consistent with recommendations made by Shaw (1972) and Polk (1982), who both specify that the hands should be parted in the middle of the body before the hands reach the pitcher's belt. From the breaking position the pitching arm continued down and backward in a smooth motion with the fingers on top of the ball for both techniques. It is of paramount importance that there be no discernible differences in the pitching styles at this stage of the action, as this will clearly indicate to the batter the type of pitch to be thrown (Thurston, 1984). The upper limb was extended to the same extent for the two throwing actions as the ball reached its lowest point (mean values for FB: elbow 2.88 rad. = 165°; wrist 3.0 rad. = 172°; mean values for CB: elbow 2.89 rad. = 166°; wrist 3.1 rad. = 178°).

From the extended position the arm was lifted into the fully cocked position. Polk (1982) referred to this position as the second balance point or power position. At this position (Figure 2) both the throwing shoulder and elbow were flexed (mean values for FB: 1.81 rad. = 104° and 1.37 rad. = 79°, respectively, mean values for CB: 1.63 rad. = 93° and 1.37 rad. = 79°, respectively). The wrist was hyperextended for both styles (FB: 2.82 rad. = 162° and CB: 2.95 rad. = 169°).

The stride toward the plate is a very important aspect of the pitching delivery. The length of the stride will vary according to the pitcher's height and build. Thurston (1984) suggested that the stride length should be approximately 80% of the standing height, and Schultzler and Atwater (1980) reported a study using professional pitchers in which the stride length was 86% of the standing height. Subjects in this study had a stride length of 154.2 cm. for the FB (82.3% of the mean height) and 152.6 cm. (81.4% of the mean height) for the CB. Shaw (1972) recommended a shorter stride length for the curveball pitch, as it enables the pitcher to pull down on the ball and impart better spin. The small difference in the distance, although in agreement with the literature, is not great enough to be significant particularly when the greater variability in the CB data is taken into consideration.

One of the key factors in maintaining accuracy is the alignment of the striding foot. Thurston (1984) suggested that the striding foot should move directly toward the plate and land with the ball of this foot on an imaginary line drawn from the pivot foot to home plate. Mean knee flexion at the point of stride-limb impact (FB: 2.3 rad. = 132° and CB: 2.4 rad. = 137°) indicated that the knee was flexed at impact for both types of pitch. The 7.0 cm (FB) and 8.4 cm (CB) alignment measures may have been the result of the over-rotation of the nonpivot limb at the first balance position. Such deviations may cause the body to open too early in the action and thus over-rotate. Thurston (1984) advocated that a
Figure 2 — Mean three-dimensional joint angular displacements (n = 6).

more open stride alignment was required for the CB and therefore the 8.4 cm deviation may be more acceptable for this pitching action.

Once the striding limb moves forward, a sequential turning of the hips and shoulders occurs and the upper limb rotates forward and outward. During this forward movement of the throwing arm the elbow is bent initially, decreasing the radius of rotation of the upper limb and enabling the arm to be moved forward more quickly than if it were extended. As the upper limb approaches the point of release, the forearm extends to increase the linear velocity of the hand, and the elbow joint reaches a mean peak angular velocity of 16.9 rad. s\(^{-1}\) for the FB and 17.2 rad. s\(^{-1}\) for the CB at 0.02s prior to release (Figure 3). The elbow joint which attains maximum angular velocity 0.02s prior to release for both techniques has therefore begun to decelerate just prior to release. The wrist joint continues to increase in velocity through release, however, particularly with the CB.
As the arm approaches the point of release, a difference in the two pitching styles is apparent. If success is to be achieved with variation in deliveries, it is essential for the pitcher to avoid telltale signs early in the action. With the FB action, the wrist moves from a position of hyperextension at the power position to a position where the hand forms almost a straight line with the forearm at release (group mean wrist angle: 3.1 rad = 178°). With the CB action, supination of the forearm occurs so that the palm of the hand almost faces the head just prior to release, and the wrist is flexed so as to enable the pitcher to pull down on the ball and impart the appropriate spin (group mean 3.28 rad. = 188°).
This finding supports photographs published by Sutton (1977) which show the ulnar side of the hand ahead of the radial side as the ball is released.

A three-quarter arm action was noted for both pitches, with mean elbow angles of $2.52$ rad. ($144^\circ$) for the FB and $2.48$ rad. ($142^\circ$) for the CB being recorded at release. For the FB the wrist and fingers were aligned behind the ball and the index and middle fingers simultaneously imparted backspin on the ball as reported by Stevenson (1985). With the CB delivery, the wrist was turned so that finger pressure could be applied to the top outer quadrant of the ball to produce a combination of forward and sideward rotation of the ball. The finger release sequence for the CB of thumb, middle finger, and index finger for five of the six pitchers supported the findings of Stevenson (1985). The emphasis on the wrist movement in the final delivery stage for the CB is illustrated by the contrasting mean angular velocities of the wrist joint of $3.1$ rad. s$^{-1}$ for the FB, and $5.8$ rad. s$^{-1}$ for the CB (Figure 3). Adduction and flexion of the wrist therefore plays a greater role in the summation of velocities for the CB when compared to the movement of wrist flexion in the FB, although it should be noted that the alignment of the forearm and hand is almost a straight line at release in both pitches (Table 2).

Sagittal plane segment contributions based on the relative horizontal velocity of the distal from the proximal segment end points expressed as a percentage of pitching velocity are recorded in Table 2.

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<th>Table 2</th>
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<tr>
<td><strong>Horizontal Segment End Point Velocity Contributions at Release</strong></td>
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<tr>
<td>for a FB and CB (m.s$^{-1}$) (n = 6)</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Acromion process (shoulder joint)</td>
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<tr>
<td>Elbow joint</td>
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<tr>
<td>Wrist joint</td>
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<tr>
<td>Hand - distal end of</td>
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<tr>
<td>middle finger</td>
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<td>Ball velocity</td>
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*Smoothing procedures, the inability to very accurately digitize the tip of the middle finger at release, and the fact that only sagittal motion was analyzed were probably the cause for less than 100% contribution being achieved.

The linear horizontal velocities of the shoulder, elbow, wrist, and middle finger at release were derived and then compared to ball velocity to give an approximation of the percentage contribution of the trunk, arm, forearm, and hand. The 38% contribution of the forearm in the CB and 35% in the FB emphasizes the importance of this segment in the movement. The percentage contributions...
of the hand at the wrist joint for the CB (31.8%) and FB (26.5%) are both higher than the 24% wrist contribution for a FB reported by Peterson (1973).

The follow-through after release is important for avoiding injury. Figure 3 shows the majority of body segments decelerating following the release of the ball for both pitching styles. The action at the release is followed by radio-ulnar pronation and shoulder medial rotation which assists in the prevention of injury. In the final stages of the action, the trunk continues to flex at the hips and the throwing arm continues across the body to finish outside the stride leg of the body. It should be stressed that radio-ulnar pronation occurs in both pitching techniques and the back of the hand never faces the batter during the delivery action for the CB as stated by Polk (1982).

References


