THREE DIMENSIONAL KINEMATICS OF THE BASEBALL PITCH

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Although the art of pitching a baseball is a complex skill involving many physical, psychological, and emotional variables, the ability to throw the baseball with high velocity is important for success at this skill.

Research suggests that arm motion is the most variable aspect of the overarm throwing pattern among subjects with different throwing abilities. However, several investigators (Atwater, 1979; Sanders, 1977; Tarbell, 1971) have noted difficulty measuring certain aspects of the arm motion. According to Atwater (1982), kinematic analyses of the overarm throw have not been extensive because this skill is clearly three-dimensional, and appropriate cinematographic techniques have not been available until recently.

The primary purpose of this study was to conduct a three-dimensional kinematic analysis of the arm motion during high velocity overarm baseball pitching, in order to : (1) measure the rate of humeral rotation and flexion/extension at the elbow and wrist joints; (2) identify kinematic variables that are significantly related to throwing velocity; and (3) determine whether significant relationships exist between selected anthropometric measurements and throwing velocity.

PROCEDURE

The subjects for this study were four high school and eight college varsity baseball pitchers. The subjects volunteered to participate, and informed consent was obtained. All subjects were male. Seven of the subjects were right-handed, and five were left-handed. Anthropometric measurements made on each subject included height, weight, upper arm length, forearm length, hand length, wrist diameter, and bi-humeral diameter. Arm measurements were made on the throwing arm.

A 16mm HyCam and two 16mm LoCam cameras were positioned at orthogonal coordinates (side, rear, and overhead), and operated at 300 frames per second as the subjects performed a maximum velocity overarm fastball pitch. A triaxial reference object was place in the field of view to establish a fixed point of origin and to scale the film data.

A Bendix digitizer was use to digitize the shoulder joint, elbow joint, wrist joint, and the baseball from 300 ms prior to release to 30 ms after release. Since the cameras were not phaselocked, the film records were synchronized to the frame closest to the point of release of the ball from the pitcher's hand. The cameras had internal timing lights, from which the true frame rate was established. A linear interpolation was used to increment the data to the same time frame.

A right-handed cartesian coordinate system was used, with the x-axis defined as the direction of the pitch, the y-axis as the vertical, and the z-axis directed toward third base. The algorithm reported by Vaughn (1985) was used to calculate linear and angular data for the throwing arm.

Pearson product-moment correlations were calculated between selected kinematic measures and the resultant ball velocity. Correlations between throwing velocity and selected anthropometric measures were also calculated. In addition, a stepwise regression analysis was done to determine how much of the total variance in throwing velocity could be explained by the effects of certain independent variables acting together.

RESULTS

The angular velocities of the arm segments and the linear velocities of the segment endpoints for the subject with the highest ball velocity are shown in Figures 1 and 2. Although magnitudes varied somewhat, velocity patterns were very similar for the 12 subjects analyzed. These figures are therefore used to aid a description of the general overarm throwing pattern for the subjects in this study.

Each of the subjects used a preparatory wind-up motion which involved rotating the trunk and the pitching arm away from the direction of the pitch. The forward movement of the arm began approximately 100 ms prior to ball release, with a rapid increase in the angular velocity of the upper arm toward the x-axis (direction of the pitch) (Figure 1). This coincided with a rapid increase in the linear velocity of the elbow (Figure 2). At the same time, the rate of outward rotation of the humerus was increasing (Figure 1), causing the forward velocity of the ball to lag behind that of the shoulder and elbow (Figure 2). As late as 70 ms before release, the ball had a very low velocity -- about 2 m.s-1 (Figure 2).

Approximately 60 ms before release, the elbow joint action changed from flexion to extension, and the rate of elbow joint extension began a rapid increase (Figure 1). The linear velocity of the wrist and the ball began to increase rapidly (Figure 2).

In the time increment between 50 ms and 30 ms before release, the rate of outward humeral rotation decreased. At the same time, the wrist joint was rapidly extended (Figure 1). The linear velocities of the shoulder and elbow (Figure 2) peaked 40 ms prior to release of the ball.

At 30 ms before release, humeral rotation changed from outward to inward. The rate of inward rotation of the humerus then increased very rapidly, peaking at release. Concurrently, the rate of rotation of the upper arm toward the x-axis was declining (Figure 1).

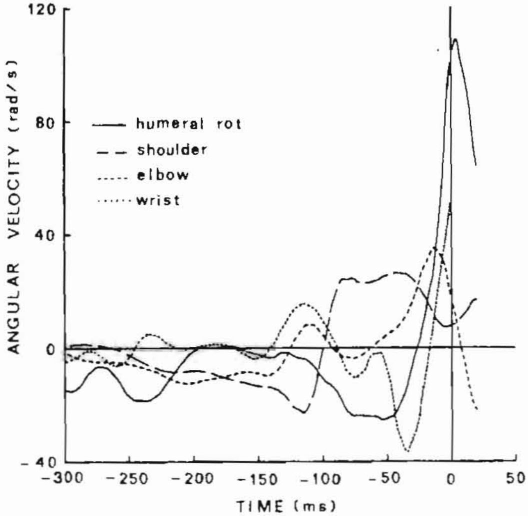

Figure 1. Joint angular velocities. Positive direction moves ball toward target -- shoulder horizontal flexion, inward humeral rotation, elbow extension, and wrist flexion.

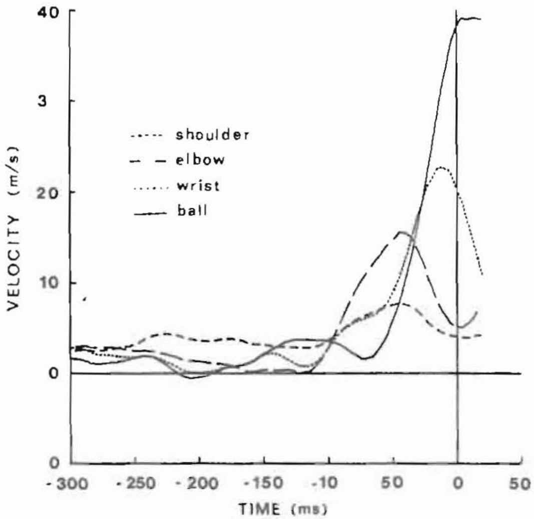

Figure 2. Linear velocities of segment endpoints in the direction of the pitch.

As the rate of elbow joint extension peaked 20 ms before release (Figure 1), the linear velocity of the wrist also reached maximum (Figure 2). This coincided with a change in the action at the wrist joint from extension to flexion (Figure 1). The rate of wrist flexion then increased rapidly, aiding the continued increase in ball velocity (Figure 2).

Mean values of selected kinematic measures at the time of release are shown in Table 1. Based on this data, the relative contributions of each joint action at the time of release were calculated, and are shown in Table 2.

The results of the Pearson Product-Moment correlations revealed significant correlations between ball velocity and six kinematic measures, shown in Table 3. The analysis revealed no significant correlations between throwing velocity and any of the anthropometric measures.

The stepwise regression analysis yielded models containing from one to five variables. The one variable model that best predicted throwing velocity was the angle between the upper arm and the x-axis at release. This variable accounted for 87% of the total variance in throwing velocity for the subjects in this study. The five-variable model, shown in Table 4, accounted for almost 99% of the total variance.

DISCUSSION

The sequential timing of the overarm baseball pitch is clearly evident in the results of this study. The more proximal segment endpoints reached maximum velocity the earliest, and each

TABLE I
SELECTED KINEMATIC MEASURES AT RELEASE (N=12)

Measure	Mean	S.D.
x-velocity of shoulder (m.s-1)	3.19	0.64
x-velocity of elbow (m.s-1)	4.86	0.84
x-velocity of wrist (m.s-1)	18.07	1.34
x-velocity of ball (m.s-1)	36.04	2.11
angular velocity of upper arm* (r.s-1)	7.87	2.13
angular velocity of forearm* (r.s-1)	42.16	3.98
angular velocity of hand* (r.s-1)	62.60	5.29
rate of humeral rotation (r.s-1)	106.83	14.90
angular velocity at elbow joint(r.s-1)	10.99	5.97
angular velocity at wrist joint(r.s-1)	58.56	11.96
angle of upper arm with x-axis (deg)	68.35	5.19
angle of forearm with x-axis (deg)	72.47	5.51
angle of hand with x-axis (deg)	73.27	6.49
angle at elbow joint (deg)	161.47	3.29
angle at wrist joint (deg)	184.40	4.29

* toward the x-axis (direction of pitch).

TABLE II
CONTRIBUTIONS OF JOINT ACTIONS TO BALL VELOCITY AT RELEASE
CALCULATED FROM MEAN VALUES FOR 12 SUBJECTS

Action	x-velocity (m.s-1)	% of ball vel.
trunk rotation, translation, and horizontal flexion at the shoulder joint	5.59	15.5%
elbow extension	4.85	13.5%
humeral rotation	15.00	41.6%
wrist flexion	10.60	29.4%
total	36.04	100.0%

TABLE III
SIGNIFICANT CORRELATIONS BETWEEN THROWING VELOCITY
AND SELECTED KINEMATIC VARIABLES

Variable	r
angle between upper arm and x-axis at release	-.93**
maximum linear velocity of elbow in x-direction	.78**
linear velocity of wrist at release	.75**
maximum angular velocity of forearm toward x-axis	.62*
angle between forearm and x-axis at release	-.59*
angular velocity at elbow joint at release	.58*

** $p < .01$ * $p < .05$

TABLE IV
BEST FIVE-VARIABLE REGRESSION MODEL FOR
DEPENDENT VARIABLE BALL VELOCITY

Variable	R Square	F	Prob > F	B Values
Regression Model	0.9877	96.43	0.0001	
Intercept				65.3464
Elbow velocity in x-direction at release				0.3894
Angle between upper arm and x-axis at release				-0.4685
Rate of humeral rotation at release				0.0472
Maximum upper arm angular velocity in x-direction				-0.0915
Forearm angular velocity in z-direction at release				-0.2066

of the next most distal segment endpoints reached peak velocity in sequence. It was also noted that the velocities of the segment endpoints declined rapidly after reaching peak velocities. The decrease in linear velocity of the shoulder and elbow coincided with a rapid increase in the rate of humeral rotation. Likewise, angular velocity at the wrist joint increased as wrist linear velocity decreased.

Whether this sequential timing occurs due to a transfer of momentum from proximal to distal segments, or simply well-timed muscle contractions is not clear.

The transfer of momentum theory proposed by Alexander and Haddow (1982), Atwater (1979), Deutsch (1971), Dobbins (1970), and Toyoshima (1974), states that as a proximal segment is slowed, part of its momentum is transferred to the distal segment, which in turn increases the angular velocity of that segment. Putnam (1983), on the other hand, concluded from her study of the kicking motion, that the decrease in the proximal segment's angular velocity does not serve to increase the angular velocity of the distal segment, but rather, this decrease occurs as a result of the influence of the distal segment's angular motion on the proximal segment. Whether the slowing of the proximal segment increases the angular velocity of the distal segment, or vice-versa, it seems clear that the actions of the proximal segments contribute to the high velocities attained by the distal segments.

The sequential joint actions may also facilitate the stretch reflex mechanism in the muscles. As the proximal segment begins its forward motion, the next most distal free hinge segment momentarily lags behind. An example of this is found in Figure 2. While the forward linear velocity of the elbow begins a rapid increase 100 ms before release, the velocity of the wrist lags behind, and does not catch up to the elbow until 40 ms before release. As seen in Figure 1, outward rotation of the humerus occurs during this same time increment. Whether this outward humeral rotation is caused by the inertial properties of the forearm, or the forceful contraction of the outward rotator muscles, it likely causes the anterior shoulder muscle group to be placed on stretch, thus enhancing a more forceful contraction of the muscles, as well as facilitating the recoil of elastic tissue (Kreighbaum & Barthels, 1985). This would lead to a higher rate of inward rotation of the humerus, and ultimately a higher release velocity.

The relative contribution of each joint action at the time of release shows smaller contributions for proximal joint actions than for those more distal. As previously indicated, however, the actions of the proximal joints likely make possible the high rates of rotation of the distal joints.

The kinematic variable which correlated the highest with ball velocity was the angle of the upper arm with the x-axis at release. The angle between the forearm and x-axis also had a significant correlation with ball velocity. Both correlations were negative, which indicates pitchers with the highest measured velocities rotated their arms farther in the direction of the pitch, forming a smaller angle with the x-axis. Since the direction a thrown ball travels is tangent to the point of release, the farther a pitcher rotates his arm and forearm in the direction of the pitch, the less he will be able to flex his wrist.

The six kinematic variables found to have significant correlations to throwing velocity each result from movements at the shoulder and elbow joints. Notably absent from this list is the angular velocity at the wrist joint. It is possible that the role of wrist flexion in maximizing overarm throwing velocity has been overrated by pitching coaches and others.

CONCLUSIONS

The following conclusions may be drawn from the results of this study.

1. Throwing velocity depends more upon kinematic variables than on anthropometric variables.
2. Highest ball velocities can be attained if pitchers maintain contact with the ball until the pitching arm rotates as far as possible in the direction of the pitch.
3. Maximizing upper arm velocity and angular velocity at the elbow joint is more important for attaining maximum ball velocity than is angular velocity at the wrist joint.

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