ANGULAR MOVEMENT CHARACTERISTICS OF THE UPPER TRUNK AND HIPS IN SKILLED BASEBALL PITCHING

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INTRODUCTION

The importance of the trunk rotation action in forceful throwing has been recognized as being critically important. Toyoshima, Hoshikawa, Miyashita and Oguri (1974) reported that with the lower body and upper body immobilized, subjects lost 36% and 47% of the ball release velocities, respectively, compared to the velocities without any restraint. However, physical restriction of one or more joints will alter the coordinated action of the unimmobilized body segments, thus the results above are questionable to unrestrained movements.

Collins (1960) placed belts with black plastic projectors on the pelvic girdle and on the upper trunk to measure the angular velocity as recorded with a side view camera. Her results indicated that the hip, upper trunk and wrist each contributed one third of the total ball velocity during the time of release (0.015 second). Atwater (1970) used a method similar to Collins's, but instead of a side view camera, she used three cameras including an overhead view. Atwater measured the angular parameters by projecting belts onto a two-dimensional reference plane. Atwater herself, as well as Ramey and Nicodemus (1977), pointed out that this kind of method can lead to erroneous values of angular parameters.

By means of a three-dimensional method, Bullard (1989) defined and examined the rotation displacement of the pelvis and upper trunk around their longitudinal body axes, the angular velocity and acceleration timing, and their relationship to the resultant ball velocity during the overarm throw. However, a completed angular kinematic investigation, not only the rotation about the longitudinal axis of the pelvis and of the upper trunk, but also the rotation about the anterior-posterior and medial-lateral axes, remain to be done.

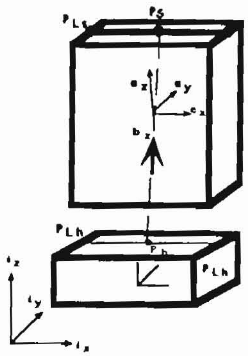
In this study, a simplified two-segment model was developed to define and examine the three rotational components of the pelvis and the upper trunk as well as the kinematic roles of these rotations in generation of high ball speed in a forceful baseball pitch.

METHODOLOGY

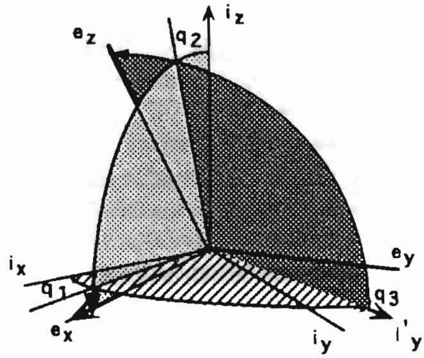
Three professional baseball pitchers were filmed by two high speed movie cameras at a speed of 250 fps while pitching with maximum effort. The joint centers of the shoulders and hips, and the throwing side elbow as well as the center of the baseball were digitized. Five trials were analyzed for each subject.

Let i_x, i_y and i_z be the unit coordinate vectors of the inertial reference frame, and e_x, e_y and e_z be the unit coordinate vectors of the upper trunk which are along the medial (right)/lateral (left), anterior (forward)/posterior (backward) and longitudinal directions of the upper trunk as shown in Figure 1a. Three Cardan angles q1, q2 and q3 generated by three successive dextral rotations about the axes along the vectors i_z, e'_y, and e_x respectively as shown in Figure 1b were defined as the counterclockwise (CCW, positive sign)/clockwise (negative sign), medial (positive sign) /lateral (LAT, negative sign) and anterior (ANT, negative sign)/posterior (positive sign) rotation angles respectively.

Points P_s and P_h are the midpoints of the shoulder line segment $P_{Ls}P_{Rs}$ and the pelvic line segment $P_{Lh}P_{Rh}$, respectively (Figure 1a). Let the vectors b_z and e_x be the unit vectors of the vector from P_h to P_s and of the vector from P_{Ls} to P_{Rs}, respectively, then a unit vector e_y which is perpendicular to both b_z and e_x can be obtained (Figure 1a). Finally, a unit vector e_z which is perpendicular to both e_x and e_y can be determined. In the same way the pelvis reference frame can be obtained.



a)



b)

Figure 1. a) Inertial and segmental reference frames; b) three rotation angles q1, q2 and q3.

Once the unit vectors e_x, e_y and e_z are obtained, their nine direction cosines can be used to form a transformation matrix that performs the transformation from the upper trunk reference frame to the inertial reference frame. This matrix also can be given by the cosines and sines of the three Cardan angles q_1, q_2 and q_3. Each element in the matrix (formed by direction cosines) is equal to the corresponding element in the matrix (formed by Cardan angles); therefore, the angles can be calculated. These angles, the coordinates of the joint centers of the shoulders and hips, the coordinates of the throwing side elbow and the coordinates of the center of the ball were smoothed by a quintic spline function. The first and second derivatives of these data were also computed from the spline function.

The ball velocity is the vector sum of the shoulder linear velocity and the ball relative velocity with respect to the shoulder joint center, and the shoulder linear velocity is mainly the net effect of the three rotation components. To estimate the kinematic contribution of the shoulder velocity to the ball velocity, a contribution ratio was defined, which is calculated by multiplying the ratio of the shoulder linear velocity to the ball velocity and the cosine of the angle between the two velocity vectors.

RESULTS and DISCUSSION

The pitch was divided into five phases by the following six important events: 1) the instant of stride foot contract (SFC); 2) the instant of beginning ball deceleration (BDC); 3) the instant of beginning ball acceleration (BAC); 4) the time of initiation of elbow extension (EE); 5) the time of initiation of humerus internal rotation (INT) and 6) the instant of ball release (REL). These abbreviations and five vertical lines indicating these events will be used on all plots. Data from the trial with the fastest ball release speed for one subject will be presented here.

In anatomic description of the body position, three orientation planes (sagittal, transverse and frontal) and three axes of motion (vertical, sagittal and frontal) are usually defined. This reference system has difficulty in describing a general orientation of the body quantitatively. The three Cardan angles were chosen here not only because they are independent of each other and can be used as generalized coordinates in both kinematic and kinetic analysis but also based on the fact that CCW rotation is the major component and lateral rotation is quite small in magnitude compared to anterior rotation in pitching. It is noticeable that the angles calculated in Figure 2 are qualitatively identical to the observation of the rotation from the anatomic point of view.

The pelvic and trunk rotations were continuously in a CCW direction during the throw (Figure 2). The upper trunk lagged behind when the hips were rotating forward near SFC. With a greater CCW acceleration the upper trunk reached the peak CCW rotation velocity at the time of BAC, and kept near this value until EE. The pelvis reached CCW peak velocity at a short time after BDC, but started to slow down sharply and clearly reached the lowest speed at EE. Thus, the trunk caught up to this rotation before INT then slowed down markedly.

For the anterior rotation, the hips initiated before SFC, and the trunk started about 50 ms later but with a greater acceleration and reached peak velocity at a short time before EE. At the time of REL, both hips and trunk ANT angles were about 40° in forward lean. The lateral rotation of the hips and upper trunk had considerably smaller magnitudes compared with other rotational components. The maximal lean angles were 13° and 29° for the hips and trunk respectively. The trunk was near neutral position at the time of SFC and had lateral lean until a short time before INT. No subject had a trunk medial (right) lean position during the entire throwing phase. The hips had a lateral lean before SFC and started to lean toward the medial direction at the middle of BDC and BAC. At the time of INT, the lateral lean angle of the hips were near zero.

The resultant velocity of the ball in the hand showed an increase from the time of SFC to an early peak 9 m/s for about 30 ms, and then slowed until the valley at about 5 m/s for 50 ms. During this early velocity initiation phase the shoulder linear speed time history was almost identical to the trend of the ball speed with smaller magnirude. The shoulder velocity contribution ratio increased from 40% to 60% just a short time after BDC and kept it above 30% until near the starting time of EE (Figure 3).

The first ball acceleration phase is from BAC to EE for about 50 ms. During the early half of this phase, the ball velocity was positively related to three rotational velocities (Figures 2 and 3). At the time the shoulder velocity reached a peak of 6 m/s, the contribution ratio attained its second maximum of 50%. During the second acceleration phase from EE to REL the ball was dramatically accelerated by elbow extension and upper arm internal rotation while the body rotations clearly slowed down.

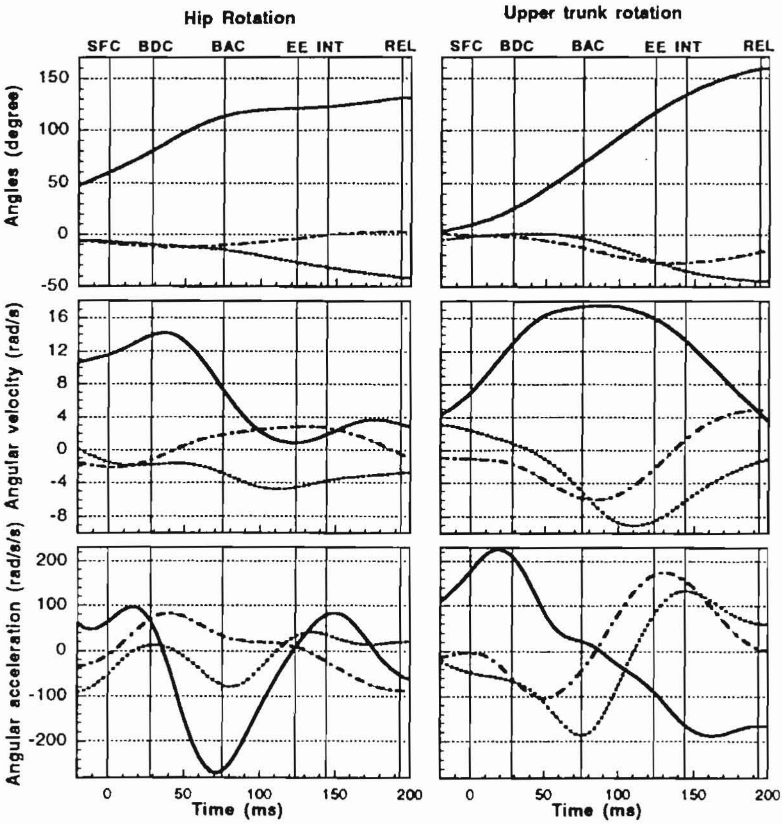


Figure 2. Angular kinematics of the hips and upper trunk. Solid lines, dotted lines and alternating dots and dashes denote the three rotation components.

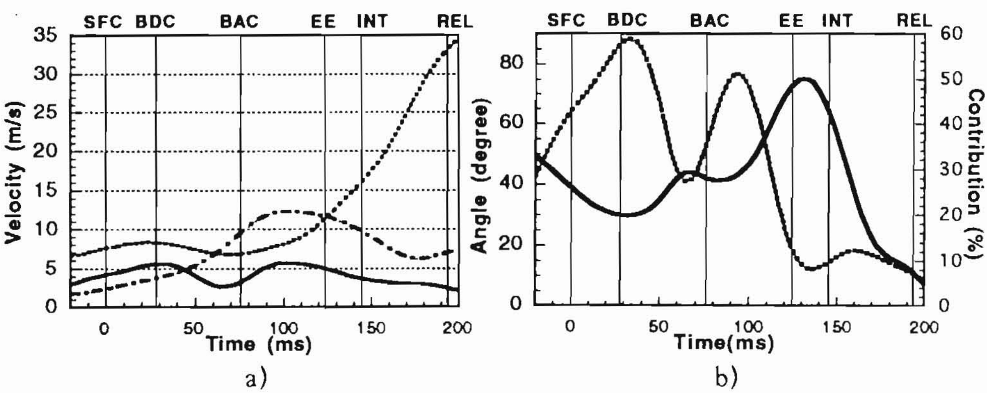


Figure 3. a) Linear resultant velocities of the ball (dotted line), elbow joint center (dot-dash line), and shoulder joint center (solid line). b) The angle (solid line, left axis scale) between the ball velocity vector and the shoulder velocity vector and the contribution ratio (dotted line, right axis scale) of the shoulder velocity to the ball velocity.

CONCLUSIONS

Using three Cardan angles, the complex angular kinematical characteristics of upper trunk and hips in overarm throwing can be revealed. The lateral rotation of the upper trunk and the anterior rotation of both upper trunk and hips had much smaller peak velocities compared to that of counterclockwise rotation. The lateral rotation of the upper trunk contributed to the ball speed mainly during a short period from the beginning of ball deceleration to the start of elbow extension. The anterior rotation of the upper trunk and hips contributed to the ball speed from the beginning of ball acceleration to the time of ball release. After the instant of stride foot contact, the hip counterclockwise rotation was the major contributor to ball velocity during the period from the beginning of ball deceleration to the start of ball acceleration. The trunk counterclockwise rotation contributed to ball speed considerably during the period from the start of ball deceleration to the start of humerus internal rotation. The contribution of the shoulder velocity to the ball velocity was about 40% at the time of SFC, 60% near the time of BDC, 35% at the time of BAC, 12% at the time of EE, 10% at the time of INT, and 8% at the time of REL.

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