AN APPROACH OF RELATIVE MOTION ANALYSIS FOR CALCULATING SEGMENTS CONTRIBUTION TO THE WORK DONE TO THE BASEBALL

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A mathematical model of the trunk and upper extremity was developed to investigate the kinetic contributions to power flow to the baseball in pitching. In the model, linear acceleration and linear velocity of the ball, for calculating power, were replaced with some anatomical angular accelerations and velocities. The model was applied to three professional baseball pitchers. Previously published data from three professional pitchers were used as input to a three-segment model of a throwing arm. Greater contributions were found in the forearm movement (18-20%) and its interaction with other segments, especially hand segment (37-46%). Though independent contribution of the upper arm movement was insignificant (2-4%), its interaction contributions by cooperating with other segments were considerable (8- 15%).

KEY WORDS: energy, power, power components, pitching.

INTRODUCTION: The contributions of joint motions (kinematic and kinetic contributions) to ball velocity in overarm throwing has been of considerable biomechanical interest. Toyoshima, Hoshikawa, and Oguri (1974) used immobilization technique to investigate it. They concluded that ball velocity accomplished by using only the forearm and hand segments reached 43% of maximum ball velocity in normal throwing employed whole body. When the upper arm was employed, ball velocity reached 53% of maximum ball velocity. Vaughan (1985) developed a mathematical model and reported that 56% of maximum wrist velocity was due to the shoulder internal rotation and 18% was due to the elbow extension. Miyanishi et al. (1996) used anatomical rotation representation approach, which was developed by Sprigings, Marshall, Elliott, and Jennings (1994), then reported that 34% of ball velocity was due to the shoulder internal rotation, 18% was due to the wrist flexion, and 15% was due to the elbow extension.
These studies facilitate our understanding for baseball pitching. However, there are some critical shortcomings. For example, the immobilization technique did not allow the thrower to throw using normal coordination and segment interaction. The approach of the anatomical angular velocity representation could reveal only instantaneous contribution, such as the instant of ball release, but not the accumulative effects by kinetic chain, which is believed to be very important in throwing. Several studies have tried to infer if transfers of energy are proximally or distally directed (Putnam, 1991). In throwing, contribution of a proximal segment may appear at a remote segment with some time-delay. The instantaneous degree of contribution does not reflect the time-delay or energy transfers between segments. The purpose of this study was, therefore, to develop a mathematical model to investigate degree of contribution of segments to ball velocity, which is available for taking account of the accumulative effects from the proximal segments.

METHODS: Previously published data from three professional baseball pitchers were used as input to a three-segment model of a throwing arm. Since the data did not include hand segment movement as well as forearm pronation/supination, a throwing hand segment were added, using the direct kinematic method with the measured anthropometric data and the angular data of forearm and wrist reported by Barrentine, Matsuo, Escamilla, Fleisig, & Andrews, J.R. (1998). In the current study, it was assumed that a ball was a point mass located at the distal end of the hand.

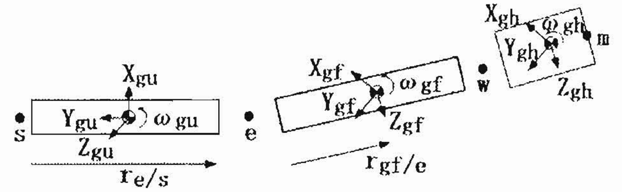

Figure1. Schematic diagram for throwing arm

First, power of the ball was calculated as scholar product of force and velocity in three-dimensions. Then, the velocity and the acceleration of the ball, one of force components, were replaced several anatomical angular velocities and angular accelerations, using relative motion representation (Hibbeler, 1998).

$$Power_{ball} = mass_{ball} * [a_m]\cdot[v_m]$$
$$v_m = v_s + (\omega_{gu} X r_{e/s}) + (\omega_{gf} X r_{w/e}) + (\omega_{gh} X r_{m/w})$$
$$a_m = a_s + (\alpha_{gu} X r_{e/s}) + (\omega_{gu} X (\omega_{gu} X r_{e/s})) + (\alpha_{gf} X r_{w/e}) + (\omega_{gf} X (\omega_{gf} X r_{w/e})) + (\alpha_{gh} X r_{m/w}) + (\omega_{gh} X (\omega_{gh} X r_{m/w})),$$

where, a and v are linear acceleration and velocity, respectively. Greek letter of ω, α are angular velocity and angular acceleration. A capital X represents cross product operation. Subscripts e, m, s, w, gf, gh, gu correspond to Figure 1.

During the final acceleration phase for the ball (cf. the area of vertical dashed line in Figure 2), the positive power and the negative power for each power term were integrated separately and considered as positive work and negative work, respectively. The mechanical meaning of positive power or work meant that force was exerted to the same direction as that of the velocity, and it was regarded as energy transfer to the ball from the hand. The negative power or work meant that force was exerted to the opposite direction as that of the velocity. It implies the energy transfer from the ball to the hand.

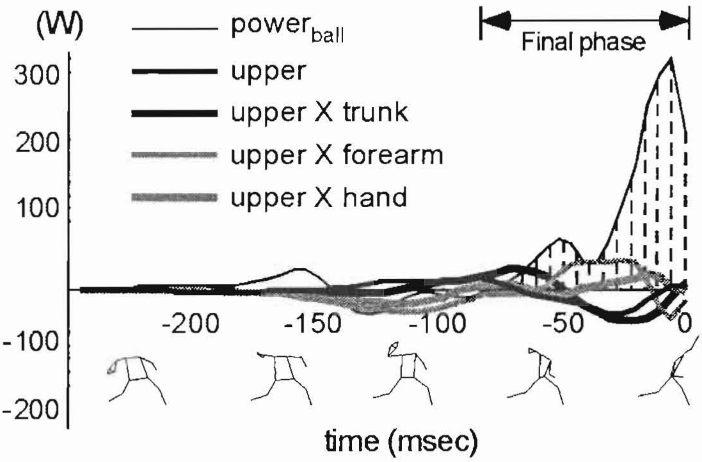

Figure 2. Mechanical power of the ball and its components concerning upper arm for a participants as an example. The instant of ball release is at 0msec. An area of vertical dotted line shows the final energy-supplying phase. A intermediate thickness of black line shows the independent power due to the upper arm. The other three lines named as 'segment X segment' indicated the interaction powers between the upper arm and the other segments.

Twenty-eight terms (4 terms concerning the linear velocity times seven terms concerning the linear acceleration) were classified into some categories, based on the segment movement. The terms concerning a certain segment, such as the dot product of $[\alpha_{gu} X r_{e/s}]$ and $[\omega_{gu} X r_{e/s}]$, were considered as independent contribution of the segment. The terms involving the different segments, such as the dot product of $[\omega_{gu} X (\omega_{gu} X r_{e/s})]$ and $[\omega_{gh} X r_{m/w}]$, were considered as interactive contribution between the segments. The terms, v_s and a_s, were considered as the terms reflecting trunk movement. The ratio of the integrated work of each term to the work done to the ball was calculated and interpreted as degree of contribution to the work done to the ball.

RESULTS AND DISCUSSION: Since all participants showed similar pattern in power-time curves, those for a participant were taken up as an example for descriptive explanation as followed.

Positive powers in power components for the throwing arm appeared sequentially from the proximal to the distal segments. First, the independent power due to the upper arm was poured into the ball during the period from -155 to -65msec (Figure 2). However, its contribution to energy pouring into the ball was negligible (2-4%), because the final energy supplying phase began at -75msec. Interactive power between the upper arm and the trunk (abbr. upper X trunk) flowed into the ball during the early part of the final energy-supplying phase (its contribution was 7-8%), then the interactive power of upper X forearm contributed energy to the ball during the middle of the final energy-supplying phase (11-15% contribution). As followed it, the interactive power of upper arm X hand functioned in the later part of the final energy-supplying phase (3-8% contribution).

In the middle of the final energy-supplying phase, at almost same time as the interactive power of upper X forearm began to contribute, the interactive powers of forearm X trunk and hand X trunk began to contribute and lasted until ball release (those contributions were 19-22% and 14-16%, respectively) (Figure 3).

The peak of the latter was observed just before the ball release.

The independent power due to the forearm and the interactive power of forearm X hand poured into the ball in the later part of the final energy-supplying phase and peaked just before the ball release (18-20% and 37-46% contributions, respectively). The latter contribution was the greatest among the power components. The hand independent power (omitted in Figures) began to contribute at 25msec before ball release and peaked at 5msec before ball release. Although the duration of the independent power due to hand was shorter than the other power components, its contribution was not negligible (9-16%). The Independent power due to the trunk was small through the pitching (1-3% contribution).

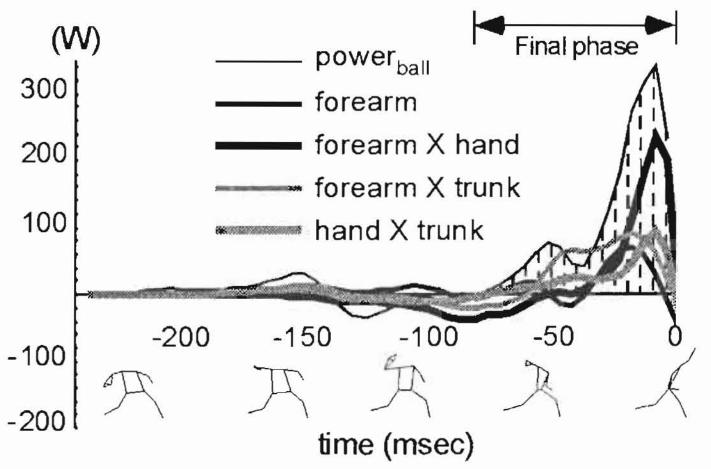

Figure 3. Mechanical power of the ball and its components concerning forearm and hand segments for the same participants as Figure 2. The instant of ball release is at 0msec. An area of vertical dotted line shows the final energy-supplying phase. A intermediate thickness of black line shows the independent power due to the forearm. The other three lines named as 'segment X segment' indicated the interaction powers.

As shown in the figures, some power components showed significant negative power. The independent power due to the upper arm showed negative values during the later part of the final energy-supplying phase (Figure 2). The ratio of its work to the total work of the ball during the final energy-supplying phase was -8 to -10 %. The interactive power of upper X trunk showed negative values at almost same timing as the independent power of the upper arm. Its work ratio to the total work of the ball during the final energy-supplying phase was -8 to -13%. The negative value suggested that the upper arm had positive angular velocity, while already decelerated. Taking it into consideration that elbow drastically extended during

the same period, the upper arm deceleration may function to set up the kinematic chain so distal segment create greater contributions.
The interactive power of forearm X trunk also showed negative values around the beginning of the final energy-supplying phase (-5 to -7%) (Figure 3). In this phase, the throwing shoulder internally rotated with elbow flexion. Therefore, the forearm rotated backward even if the trunk moved forward. The movement must be necessary to stretch rotator cuff muscles to throw a ball faster. The negative value in the forearm X trunk interaction may also function to set up the kinematic chain.

CONCLUSION: This study developed a mathematical model to investigate on the segments contribution to the work done to the ball during baseball pitching, using the relative motion analysis. This approach can account for the contribution of the interaction between segments and the accumulative effects by the kinetic chain, in the viewpoint of mechanical energy flow. It does not require using the inverse dynamics with some estimated physical inertia parameters inducing the estimation error. To combine the current approach with the traditional kinematic and kinetic approaches including the inter-segments energy flow may let us understand the pitching mechanics better.

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