# INFLUENCE OF DIFFERENT SHOULDER ABDUCTION ANGLES DURING BASEBALL PITCHING ON THROWING PERFORMANCE AND JOINT KINETICS

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The relationships between shoulder abduction angle at ball release and wrist velocity and several injury-related kinetic parameters were investigated. Based on kinematic data of nine overhand and three-quarter-hand pitchers, several pitching motions with different shoulder abduction angles from the original were simulated. The wrist velocity and several injury-related kinetic parameters for the motion with 90 degree shoulder abduction angle at ball release were compared with those for the motions with other shoulder abduction angles. The 90 degree abduction angle maximised wrist velocity and decreased elbow joint kinetics, but did not always decrease shoulder joint kinetics.

KEY WORDS: wrist velocity, force, torque, simulation, baseball, pitching, throwing

INTRODUCTION: For throwing and the one-hand striking motion, it has been recommended that the player's elbow should be high as his/her shoulders' during the final acceleration phase (Atwater, 1979). Baseball pitching is a good example and has been used in several technical text books. There are two major concerns: maximising performance and minimising stress on the throwing arm (Braatz and Gogia, 1987). For the former, there has been no quantitative study focused on whether the elbow position (shoulder abduction angle of 90 degrees) actually maximises the pitched ball speed. To consider the joint stress, investigating joint kinetics may be important. Fleisig, Andrews, Dillman and Escamilla (1995) investigated throwing arm kinetics during baseball pitching and suggested potential relationships between kinetic parameters and throwing injuries. Although this result is highly suggestive, there has been no study investigating relationship between the shoulder abduction angle and throwing arm kinetics during pitching. The purposes of this study were to compare throwing performance achieved with 90 degrees shoulder abduction at the instant of ball release and throwing performances achieved without 90 degrees shoulder abduction, and to compare joint kinetics (forces and torques) with the 90 degrees of shoulder abduction with those without the 90 degrees of shoulder abduction.

METHODS: Data Collection: Nine overhand and three-quarter-hand professional baseball pitchers (mean height 1.82 ± 0.04 m, mean mass 78.3 ± 9.1 kg; mean age 22.6 ± 3.0 years) were videotaped by two high-speed cameras (HSV-400, NAC, Tokyo, Japan) at 200 Hz during pitching. Ball speed was recorded with a radar gun (PM-4A, Decatur Electronics, Inc., Decatur, IL). After the videotaping, the data set for the pitch with the fastest ball that struck the strike zone for each subject was selected for analysis. Video images were superimposed on the display of a personal computer. The third knuckle of the throwing arm, throwing wrist, throwing elbow, both shoulders, both hips, and the ball were manually digitised. In this study, data were analysed from 40 frames (0.2 s) before the instant of ball release to 10 frames (0.05 s) after the instant of ball release. This duration corresponded to the duration from approximately 0.05 s before the lead foot contact to almost the same instant of shoulder maximum internal rotation. The three-dimensional location of each point was calculated using the DLT method and the data were smoothed using a fourth-order zero-lag Butterworth filter. The resultant cut-off frequency was decided for each direction in the global reference frame for each point, by the residual analysis method (Winter, 1990). The range of the cut-off frequency was 6.2 Hz (left hip) - 13.6 Hz (right wrist). Four wires with four calibration markers were suspended vertically and were positioned so that the markers made a matrix approximately 2.0 m X 2.0 m X 1.5 m in size. The root mean square error in calculating the positions of the calibration markers was 0.3 cm.

**Calculation of Kinematics:** Four kinematic parameters for the throwing arm were calculated using basically the same methods as Feltner and Dapena (1986). Elbow flexion angle was the angle between the distal directions of the upper arm and forearm. Shoulder abduction angle was defined as the angle subtracting 90 degrees from the angle between the distal direction of upper arm and the inferior direction of upper torso, which was from mid-shoulder to mid-hip. Shoulder horizontal adduction angle was defined as the angle between the distal direction of the upper arm and the unit vector from the mid-shoulder to the right shoulder, in the transverse plane. Shoulder external rotation angle was calculated as the angle subtracting 90 degrees from the angle between the distal direction of the forearm and the anterior direction of the upper torso, in a plane perpendicular to the upper arm. These angular displacements were differentiated for calculating the corresponding angular velocities. Due to limitations in computer resolution of video image, the peak of the wrist velocity was used as a criterion of throwing performance.

**Joint Kinetics:** Resultant forces and torques on the throwing shoulder and the throwing elbow were calculated using the same method previously reported, which used inverse dynamics of Newton equations (Feltner and Dapena, 1986; Fleisig et al., 1995). The mass of a baseball was set equal to 0.145 kg and moment of inertia of the ball was assumed to be negligible. Due to limitations in computer resolution of video image, the masses of the hand and the ball were assumed to be at the wrist. For the inertia properties of the body segments, Ae's regression model (Ae, Tang, & Yokoi, 1992) applying Jensen's method to Japanese athletes was used. The proximal resultant joint force and torque exerted on each link was calculated using the previously reported method (Feltner and Dapena, 1986; Fleisig et al., 1995), beginning with the ball. The resultant torques of the elbow and shoulder calculated in the global reference coordinates were, then, transformed into forearm reference frame and upper torso reference frame, respectively (Fleisig et al., 1995).

**Simulated Motion:** Amplitude of the shoulder abduction angle during pitching was changed so that the angle at the instant of ball release was equal to a target angle, but the other angular displacements and all angular velocities including the shoulder abduction angular velocity were kept the same. Target angles were every 10 degrees from 50 degrees to 130 degrees. Using the changed shoulder abduction angle ($\varphi$) and the shoulder horizontal adduction angle ($\phi$), new elbow position ($E_n$) was calculated:

$$E_n = S_f + Lu\,[\cos(\varphi)\sin(\$), \sin(\varphi), \cos(\varphi)\cos(\phi)]^T \bullet [Rt]$$

where $S_f$ is the shoulder position, Lu is length of upper arm, T denotes the transpose of matrix, and [Rt] is a matrix of the upper torso reference coordinates. After calculating new elbow position, upper arm local reference frame was re-calculated. New wrist position ($W_n$) was calculated using the new upper arm local reference frame [Ru'], new elbow position ($E_n$), elbow flexion angle ($\eta$), and shoulder external rotation angle (8):

$$W_n = Lf\,[\cos(-p/2 + \eta)\sin(\theta), \cos(-p/2 + \eta)\cos(\theta), \sin(-p/2 + \eta)]^T \bullet [Ru'] + E_n\,,$$

where Lf is length of forearm, and T denotes the transpose of matrix. These re-calculated joint locations were merged to the measured trunk reference points (both shoulders and both hips). The angular displacements, angular velocities, wrist velocities, forces and torques were re-calculated for these simulated motions.

**Data Reduction and Statistics:** After calculating all above parameters, to facilitate interpretation of the results, the definition of the shoulder abduction angle was changed so that a posture where the arm is hung down vertically was defined as 0 degrees and a posture where the shoulder is abducted horizontally was defined as 90 degrees.

Previous study suggested that elbow medial force, elbow flexion torque, elbow varus torque, shoulder anterior-posterior force, shoulder superior-inferior force, shoulder compressive force, and shoulder horizontal adduction torque may be related to throwing injuries (Fleisig et al., 1995; Fleisig and Barrentine, 1995). Peaks of these parameters were used in the current study. Analysis of variance methods were used on these kinetic parameters and the wrist velocity to assess the significant differences among the various simulated motions. Only p values $< .01$ were considered significant. Post hoc comparisons with control (Dunnett's test) were conducted with the p values $< .05$. The motion with the 90 degrees shoulder abduction angle at the instant of ball release was used as a control.

**RESULTS AND DISCUSSION:** Mean ball speed measured by the radar gun in the current study was 35.7 ± 1.22 rnls and consistent with previous studies for the professional and college pitchers (33.5 rnls - 38 rnls in the studies by Barrentine, Matsuo, Escamilla, Fleisig, & Andrews, 1998; Dillman, Fleisig, & Andrews, 1993; Feltner, 1989). Peak of the wrist velocity for the original in the current study was 16.2 ± 0.5 m/s. Mean shoulder abduction angle at the instant of ball release for the original was 100.7 degrees ± 12.5 degrees. The value is a little greater than previous studies (90 degres - 95 degrees in the studies by Atwater, 1979; Dillman et al., 1993; Feltner and Dapena, 1986; Fleisig et al., 1995). In the following sub-sections, please note that the 100 degrees condition can be substituted for the original, since mean shoulder abduction angle for the original was 100.7 degrees.

**Wrist Velocity:** Means of the peak of wrist velocities of the simulated motions with standard errors are shown in Figure 1. The maximum wrist velocity among the simulated motions was found in the motion under the 90 degrees condition (16.3 ± 0.6 rnls), but significant differences between the 90 degrees condition and the other conditions were found only in the 50, 60, and 130 degrees conditions. It seems that abducting shoulder around 90 degrees is important to increase the throwing performance.

**Elbow Kinetics:** Fleisig et al. (1995) and Fleisig and Barrentine (1995) suggested that elbow medial force and elbow varus torque involved elbow medial and lateral injuries. Figure 2 shows the peak of elbow varus torque for each condition. The minimum of the peak of the elbow varus torque was observed in the 80∫ condition. Significant differences between the 90 degrees condition and the other conditions were found only in the 120 and 130 degrees conditions. The elbow varus torque in the 90 degrees condition was almost the same as the minimum value. The same trend was seen for the elbow medial force. For the elbow kinetics, 90 degrees shoulder abduction required relatively lower force and torque.

**Shoulder Kinetics:** Figure 3 shows the peak of the shoulder anterior force for each condition. Although the minimum of the peak of the shoulder anterior force was found in the 110 degree condition, significant differences between the 90 degree condition and the other conditions were found only in the 50 and 60 degree conditions. The same trend was found for the shoulder superior and inferior forces, but the minimums of both forces were found in the 100 degree condition and no significant difference was found. Figure 4 shows the peak of the shoulder compressive force. The shoulder compressive force decreased with the increase of the shoulder abduction angle. Significant differences between the 90 degree condition and the other conditions were found in the 50 and 60 degree conditions. Shoulder horizontal adduction torque had the same trend as shoulder compressive force.

**CONCLUSION:** It is suggested that the 90 degree shoulder abduction angle at ball release maximise the wrist velocity and decreased the elbow joint kinetics. It did not always minimise the shoulder joint kinetics. It is suggested that overhand and three-quarter hand pitchers should pay attention to keep their throwing shoulder abduction angle during the acceleration phase at around 90 degrees in their practice. This is a good choice of angle to increase ball speed and to minimise risk of the throwing injuries. There may be an optimal shoulder abduction angle for each subject, which maximises performance and minimises joint stress. Further studies investigating this issue are needed. The results in the current study should not be extended to sidearm or underhand pitchers, because subjects in this study were only overhand and three-quarter-hand pitchers. These delivery types of pitching should also be investigated.

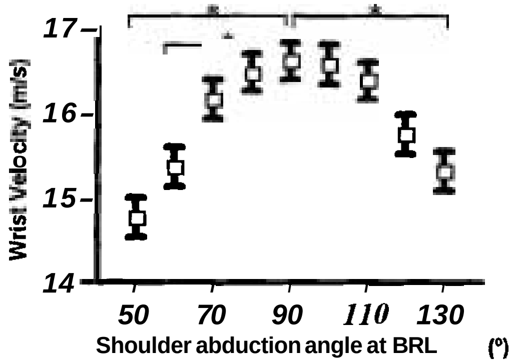


Fig.1 Peak wrist velocity

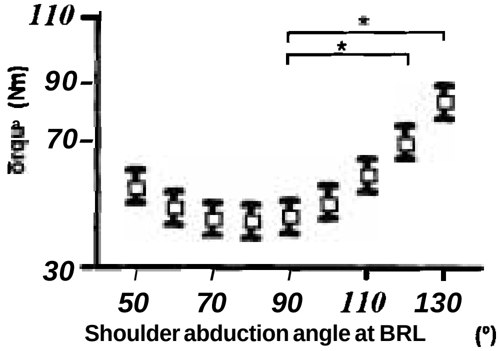


Fig.2 Peak of elbow varus torque

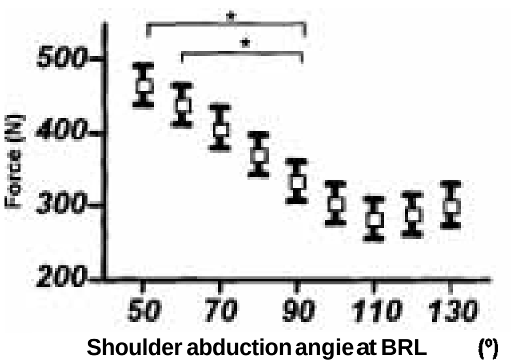


Fig.3 Peak of shoulder anterior force

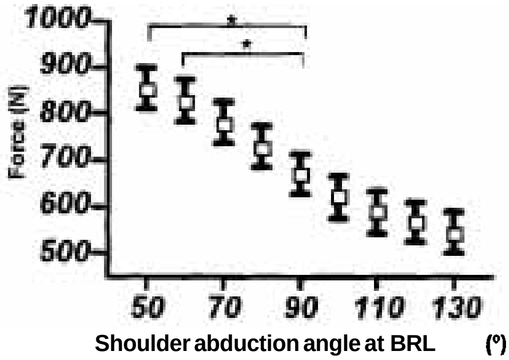


Fig.4 Peak of shoulder compressive force

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