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# The relationship between age and baseball pitching kinematics in professional baseball pitchers

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**Abstract**

Joint range of motion and physical capacities have been shown to change with age in both throwing athletes and non-athletes. The age of professional baseball pitchers could span from late teens to mid-40s. However, the effects of age on the pitching kinematics among professional baseball pitchers are still unknown. In this study, 67 healthy professional baseball pitchers were tested using a 3D motion analysis system. Their mean age was $23.7 \pm 3.3$ years (range 18.8–34.4). The 12 pitchers more than one standard deviation older than the mean (i.e., older than 27.0 years) were categorized into the older group, and the 10 pitchers more than one standard deviation younger than the mean (i.e., younger than 20.4 years) were defined as the younger group. In all, 18 kinematic variables (14 position and 4 velocity) were calculated, and Student's *t*-tests were used to compare the variables between the two groups. Six position variables were found to be significantly different between the two groups. At the instant of lead foot contact, the older group had a shorter stride, a more closed pelvis orientation, and a more closed upper trunk orientation. The older group also produced less shoulder external rotation during the arm cocking phase, more lead knee flexion at ball release, and less forward trunk tilt at ball release. Ball velocity and body segment velocity variables showed no significant differences between the two groups. Thus, differences in specific pitching kinematic variables among professional baseball pitchers of different age groups were not associated with significant differences in ball velocities between groups. The current results suggest that both biological changes and technique adaptations occur during the career of a professional baseball pitcher.


*Keywords:* Kinematics; Age; Biomechanics; Baseball; Pitch

## 1. Introduction

The baseball pitching biomechanics of adults have been extensively studied (Barrentine et al., 1998; Dillman et al., 1993; Elliott and Grove, 1986; Feltner and Dapena, 1986; Fleisig et al., 1995, 1996; MacWilliams et al., 1998; Matsuo et al., 2001; Pappas et al., 1985, 1995; Sakurai et al., 1993; Stodden et al., 2005; Vaughn, 1985; Werner et al., 1993). These studies have shown that baseball pitching is a highly demanding task, and proper pitching mechanics are very important in preventing pitching injuries and improving or maintaining performance. A previous study (Fleisig et al., 1999) of baseball pitching among various levels of development revealed that adult pitchers did not demonstrate different position or temporal patterns than younger pitchers. All the kinetic variables that were analyzed increased significantly with competition level, which was most likely due to increased strength and muscle mass in the higher-level athletes.

Aging changes the physical capacities and therefore the performance of athletes considerably. In a study of track and field athletes, Fung and Ha (1994) found that the running, jumping, and throwing events most affected by age were the 400-m run, long jump, and javelin, respectively. There are systematic relationships between

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the age of peak performance and specific athletic events. Stones and Kozma (1984) developed a second-order polynomial model to quantitatively describe the relationship between age and performance in track and field events. The model fit the data very well and accounted for approximately 81% of the mean variances. Schulz and Curnow (1988) found that performance in swimming, sprinting, jumping, and tennis tended to peak in the early to mid-20s, whereas performance in long-distance running, baseball, and golf peaked in the late 20s and early 30s. In major league baseball players, the athletic performance on key indicators (e.g., ERA, Strikeouts) rises relatively quickly from age 19 to a peak age of 27 and declines gradually thereafter (Schulz et al., 1994).

The age of professional baseball pitchers ranges from late teens to mid-40s. Even though some researchers have investigated the relationship between age and pitching performance in major league baseball pitchers (Schulz et al., 1994) and the pitching biomechanics among various development levels (Fleisig et al., 1999), the variations in pitching mechanics of professional baseball pitchers among different ages are still unknown. Therefore, the purpose of this study was to investigate the differences of pitching kinematics between two different age groups of professional baseball pitchers. We hypothesized that kinematic variables will be significantly affected by age.

## 2. Methods

Sixty-seven professional baseball pitchers were tested in an indoor laboratory. All participants had no previous history of neuromusculoskeletal disorders. The average age of the subjects was $23.7 \pm 3.3$ years (range 18.8–34.4). Those subjects older than one standard deviation above the mean ($>27.0$ years) were categorized into the "older group", and those subjects younger than one standard deviation below the mean ($<20.4$ years) were defined as the "younger group". There were 12 subjects in the older group and 10 subjects in the younger group. Subject information for the two groups were compared in Table 1. Prior to the testing, each subject signed a consent form approved by the Institutional Review Board of the American Sports Medicine Institute.

Data were collected by following protocols described in previous studies (Barrentine et al., 1998; Dillman et al., 1993; Escamilla et al., 1998; Fleisig et al., 1995, 1996, 1999; Matsuo et al., 2001; Nicholls et al., 2003; Stodden et al., 2001, 2005). In all, 15 reflective markers (2.54 cm in diameter) were attached on the subject's anatomical landmarks, including 12 markers placed bilaterally on the proximal end of the third metatarsal, lateral malleolus, lateral femoral epicondyle, greater femoral trochanter, lateral superior tip of the acromion, and lateral humeral epicondyle. One marker was placed on the ulnar styloid of the non-throwing hand. The other two markers were placed on the ulnar styloid and radial styloid. After the markers were attached to his body, the pitcher was given ample time for his normal warm-up routine. When the subject was ready, data were collected with the subject pitching off an Athletic Training Equipment Company (ATEC, Santa Cruz, AZ) indoor pitching mound towards a strike zone target located above home plate 18.4 m away from the pitching rubber. Each subject was instructed to pitch 10 fastballs with maximal effort. The subject was given 30–60 s of rest time before each pitch.

Table 1
Subject characteristics

| | Younger group ($n=10$) | Older group ($n=12$) |
|---|---|---|
| Age (years)* | $19.7 \pm 0.5$ | $29.5 \pm 2.0$ |
| Body height (cm) | $189.3 \pm 4.9$ | $189.4 \pm 6.3$ |
| Body weight (kg) | $93.5 \pm 10.3$ | $93.3 \pm 8.2$ |
| Ball velocity (mps) | $37.6 \pm 1.2$ | $37.0 \pm 1.3$ |
| Professional level* | | |
| Major league | 0 | 10 |
| Minor league AA | 1 | 2 |
| Minor league A | 6 | 0 |
| Minor league Rookie Ball | 3 | 0 |

*Significant differences ($p < 0.01$).

Ball velocity was measured using a Jugs radar gun (Jugs Pitching Machine Company, Tualatin, OR) from behind the home plate. An automatic digitizing, six-camera, three-dimensional motion analysis system (Falcon Analog System, Motion Analysis Corporation, Santa Rosa, CA) was employed to track the pitching motion. The sampling rate of each camera was 240 frames/s. Root mean-square error in calculating marker location was 1.0 cm (Fleisig et al., 1996).

Position data were filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 13.4 Hz. Kinematic variables were calculated using the same methods previously described (Dillman et al., 1993; Fleisig et al., 1996; Escamilla et al., 1998). Linear and angular velocities were calculated using the five-point central difference method. For each subject, data from the five highest velocity pitches that hit the strike zone were averaged and used for data analysis. In all, 18 position/velocity variables were analyzed including eight variables at lead foot contact, four variables during the arm cocking phase, two variables during the arm acceleration phase, and four variables at ball release. Position variables are illustrated in Fig. 1. Descriptive statistics such as means and standard deviations of all the variables were presented in Table 2. A Fisher's exact

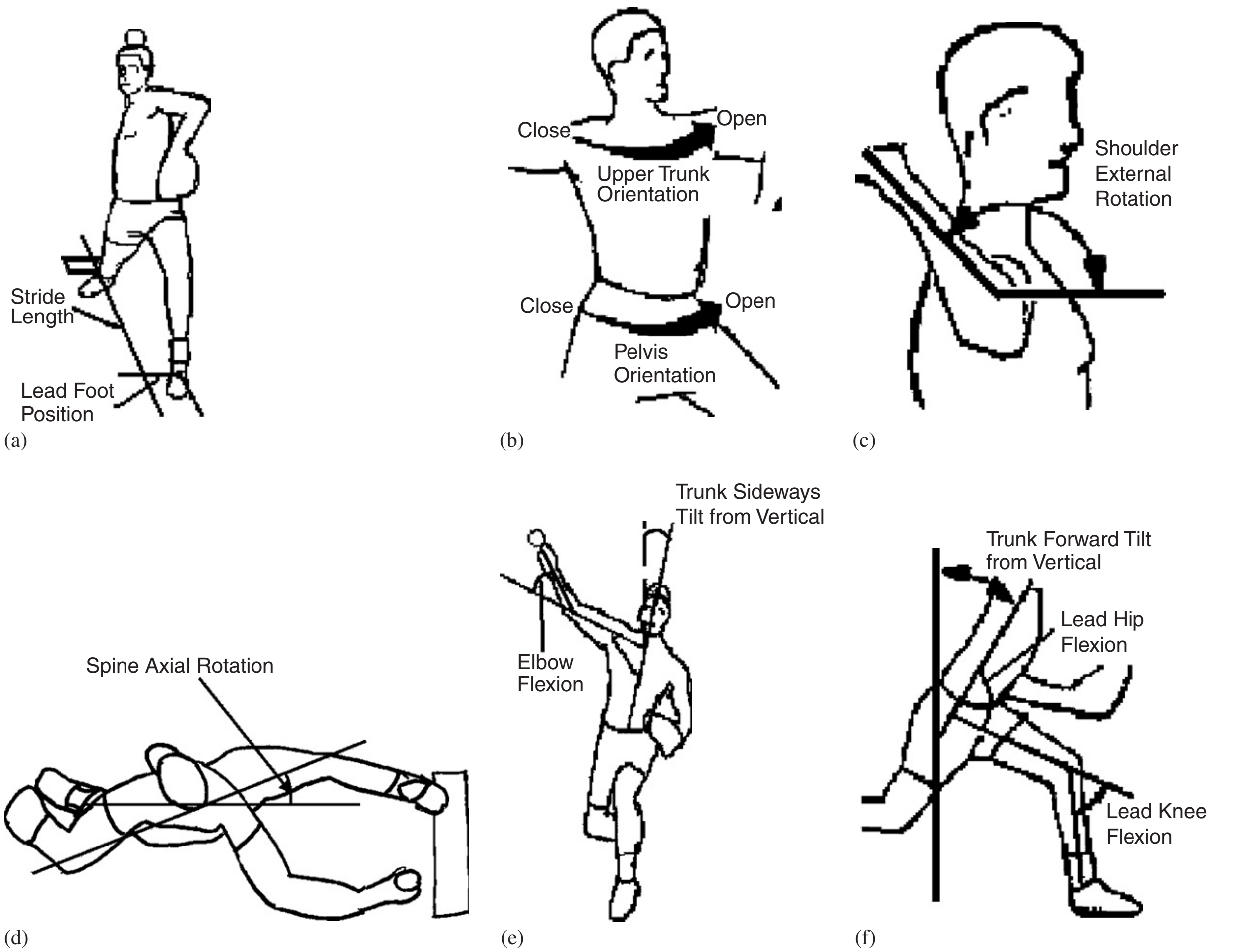


Fig. 1. Definition of kinematic parameters: (a) stride length and lead foot position, (b) pelvis and upper trunk orientation, (c) shoulder external rotation, (d) spine axial rotation, (e) elbow flexion and trunk sideways tilt from vertical, and (f) trunk forward tilt from vertical, and lead knee flexion.

test was conducted to test the difference of the distribution of competition levels between the two groups. Student's *t*-tests were performed to examine the differences in age, body height, body weight, and ball velocity between the two groups. Student's *t*-tests were also used to evaluate the difference of the position/velocity variables between the two groups. Significance levels at both 0.01 and 0.05 were reported. All data analyses were performed using SPSS 10.0.5 software (SPSS Inc., Chicago, IL).

## 3. Results

The average age of the older group was approximately 10 years older than that of the younger group. There was no significant difference between the two groups in body height, body weight, and ball velocity. Players in the older group played at higher levels (Table 1). In fact, an analysis of date-of-birth data provided on Major League Baseball's website (www.mlb.com) showed that the mean age of the older group in this study (29.5) was very similar to the mean age of current Major League Pitchers (30.0).

Six position variables were found to be significantly different between the two groups (Table 2). At lead foot contact, the stride length of the younger group was approximately 5% of body height more than that of the older group. Both the pelvis and upper trunk of the older group were in more "closed" positions. In this study, the trunk is "closed" when the posterior aspect of the upper trunk is visible to the batter (Stodden et al., 2005). The differences in mean values between the two groups were 13.7° and 11.0° for the pelvis and upper trunk, respectively. During the arm cocking phase, the maximum shoulder external rotation of the younger group was 9.8° more than that of the older group. At ball release, the older group flexed the lead knee 12.1° more than the younger group did. The trunk of the younger group was tilted forward approximately 8.1° more than that of the older group.

There were no significant differences between the two groups in the four velocity variables: maximum pelvis angular velocity during arm cocking, maximum upper

Table 2
Comparison of position/velocity variables between younger and older groups

| Variables | Mean ± STD | |
|---|---|---|
| | Younger group ($n = 10$) | Older group ($n = 12$) |
| *Lead foot contact* | | |
| Stride length (% height)** | 82.5 ± 4.1 | 77.3 ± 5.1 |
| Lead foot position (cm) | −22.2 ± 14.0 | −21.7 ± 6.1 |
| Pelvis orientation (°)* | 37.2 ± 12.3 | 23.5 ± 6.1 |
| Upper trunk orientation (°)* | −13.0 ± 9.4 | −24.0 ± 7.4 |
| Shoulder external rotation (°) | 47.7 ± 33.0 | 47.5 ± 32.0 |
| Lead knee flexion (°) | 38.5 ± 11.4 | 43.8 ± 7.4 |
| Elbow flexion (°) | 94.6 ± 23.1 | 89.4 ± 8.7 |
| Spine axial rotation (°) | −50.0 ± 8.9 | −47.0 ± 8.5 |
| *Arm cocking phase* | | |
| Maximum pelvis angular velocity (°/s) | 535.3 ± 79.8 | 592.3 ± 83.2 |
| Maximum upper trunk angular velocity (°/s) | 1098.8 ± 70.0 | 1143.2 ± 125.5 |
| Maximum shoulder external rotation (°)* | 182.6 ± 4.3 | 172.8 ± 6.4 |
| Maximum elbow flexion (°) | 105.9 ± 16.9 | 104.8 ± 11.4 |
| *Arm acceleration phase* | | |
| Maximum elbow angular velocity (°/s) | 2375.9 ± 289.4 | 2344.7 ± 160.9 |
| Maximum shoulder internal rotation angular velocity (°/s) | 7253.5 ± 1324.1 | 6642.0 ± 668.7 |
| *Ball release* | | |
| Lead knee flexion (°)** | 27.8 ± 12.5 | 39.9 ± 13.7 |
| Trunk forward tilt from vertical (°)* | 36.8 ± 4.2 | 28.7 ± 7.2 |
| Trunk sideways tilt from vertical (°) | 17.9 ± 6.1 | 22.9 ± 10.2 |
| Lead hip flexion (°) | 102.2 ± 5.8 | 104.4 ± 7.3 |

*Significant differences ($p < 0.01$).
**Significant differences ($p < 0.05$).

trunk angular velocity during arm cocking, maximum elbow angular velocity during arm acceleration, and maximum shoulder internal rotation angular velocity during arm acceleration.

## 4. Discussion

In all, 6 out of 14 position variables were found to be significantly different between the two groups: stride length, upper trunk and pelvis orientation angles at lead foot contact, maximum shoulder external rotation angle during arm cocking phase, and lead knee angle and trunk forward tilt angle at ball release. The joint range of motion of the human body has been demonstrated to degrade with age among both the general population (Allander et al., 1974; Barnes et al., 2001; Clarke et al., 1975) and young overhead athletes (Kibler et al., 1996; Meister et al., 2005). Given the fact that the body height, body weight, and ball velocity were not significantly different between these two groups, these results implied that age is very likely the most important contributor to these differences.

Baseball pitchers at the professional level (Bigliani et al., 1997; Brown et al., 1988; Crockett et al., 2002; Ellenbecker et al., 2002), college level (Baltaci et al., 2001; Reagan et al., 2002), and youth level (Meister et al., 2005) have all been found to demonstrate significantly greater shoulder external rotation in the dominant arm. Similar results have been reported in professional tennis players (Schmidt-Wiethoff et al., 2003) and javelin throwers (Herrington, 1998). Crockett et al. (2002) compared the shoulder external rotation between the dominant and non-dominant arms in both professional baseball pitchers and non-athletes. They found that the pitchers demonstrated a significant increase in the dominant shoulder versus the non-dominant shoulder external rotation, while the non-athletes demonstrated no significant difference in external rotation between shoulders. It was also found that shoulder external rotation was significantly greater in the pitchers. They concluded that throwing during childhood might lead to a significant increase of shoulder external rotation. Interestingly, in the current study, we found that throwing shoulder maximum external rotation during arm cocking phase decreased with age. This finding agrees well with the results of Meister et al. (2005). They reported that among youth baseball players, even though the dominant arm demonstrated significantly greater external rotation than the non-dominant arm, flexion and total range of motion of the shoulder significantly decreased as age increased, and external rotation showed a trend of decreasing with age. Therefore, it would be reasonable to hypothesize that shoulder range of motion decreases with age due to biological development of the human body; while for the dominant arm of baseball players, the decrease of shoulder external rotation is delayed or slowed down as a response to pitching as such it could conserve more external rotation than the non-dominant arm.

During a fastball pitch, the trunk starts to "open" (i.e. anterior aspect of upper trunk visible to batter) and the lead knee begins to extend just prior to maximum shoulder external rotation. These motions continue throughout the rest of the pitch (Escamilla et al., 1998). Matsuo et al. (2001) compared the kinematic variables between two different pitch velocity groups. In their study, there was no significant difference in age between groups. They reported that during the arm acceleration phase, the high-velocity group extended their knees a greater amount and through a larger range compared to the low-velocity group. It was also shown that in javelin throwing, a higher release velocity was associated with a less-flexed lead knee (Bartlett et al., 1996; Morriss and Bartlett, 1996; Whiting et al., 1991). These findings suggested that the extension of the lead knee helps brace and stabilize the lead leg, which may enhance the ability of the trunk to rotate forward over the braced lead leg more effectively, and therefore help transfer energy through the trunk to the throwing arm. In the current study, the younger group extended the lead knee more than the older pitchers did at the instant of ball release. Furthermore, the younger group demonstrated a longer stride and greater trunk forward tilt angle at the time of ball release. These differences may be due to some combination of flexibility, strength, or technique. However, these differences were not associated with higher ball velocities. Further studies are needed to explain these differences.

Fleisig et al. (1999) reported that among four baseball competition levels (youth, high school, college, and professional), only one of the 11 kinematic position variables showed significant differences, while all five velocity variables showed significant differences. Moreover, all eight kinetic variables increased significantly with competition level. They suggested that the increases in the kinetic and velocity variables were due to increased strength and muscle mass in the higher-level pitchers. However, in the current study, none of the four angular velocity variables (pelvis, upper trunk, shoulder, and elbow) were significantly different between the two groups, which was consistent with the finding that ball velocity did not differ between the groups. Interestingly, two position variables that were previously found to be significantly correlated with ball velocity, i.e., maximum shoulder external rotation and trunk forward tilt at ball release (Matsuo et al., 2001), were degraded in the older group. These seemingly contradictory results suggested that the pitchers in the older group might have altered their coordination to compensate for the deterioration of the crucial position variables. More work is needed to investigate what strategies the older pitchers used to maintain ball velocity. One of the possible studies would be to investigate the difference of the temporal variables between the older and younger pitchers. We hypothesize that older pitchers are able to optimize the temporal relationship between various important kinematic events so that they can still maintain ball velocity in spite of compromised kinematics. Another possibility is that there may be kinetic differences. Such studies would provide further insight into differences between younger and older elite pitchers.

The upper extremity model that was used to calculate the shoulder rotation angles might be a limitation of the current study. In this model, shoulder movements were calculated using projection angles. However, we believe this model is sufficient for the objectives in the current study. In conclusion, the significant kinematic differences found between two age groups significantly changed the pitching kinematics among professional baseball pitchers, and these differences were not associated with ball velocity. The current results suggest that both biological changes and technique adaptations occur during the career of a professional baseball pitcher.

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