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Technical note

Kinematic and kinetic comparison of baseball pitching among various levels of development

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Abstract

Proper biomechanics help baseball pitchers minimize their risk of injury and maximize performance. However previous studies involved adult pitchers only. In this study, 23 youth, 33 high school, 115 college, and 60 professional baseball pitchers were analyzed. Sixteen kinematic (11 position and five velocity), eight kinetic, and six temporal parameters were calculated and compared among the four levels of competition. Only one of the 11 kinematic position parameters showed significant differences among the four levels, while all five velocity parameters showed significant differences. All eight kinetic parameters increased significantly with competition level. None of the six temporal parameters showed significant differences. Since 16 of the 17 position and temporal parameters showed no significant differences, this study supports the philosophy that a child should be taught 'proper' pitching mechanics for use throughout a career. Kinetic differences observed suggest greater injury risk at higher competition levels. Since adult pitchers did not demonstrate different position or temporal patterns than younger pitchers, increases in joint forces and torques were most likely due to increased strength and muscle mass in the higher level athlete. The greater shoulder and elbow angular velocities produced by high-level pitchers were most likely due to the greater torques they generated during the arm cocking and acceleration phases. The combination of more arm angular velocity and a longer arm resulted in greater linear ball velocity for the higher level pitcher. Thus, it appears that the natural progression for successful pitching is to learn proper mechanics as early as possible, and build strength as the body matures.

Keywords: Biomechanics; Kinematics; Kinetics; Youth; Professional

1. Introduction

The best time to try to prevent pitching injuries is at the beginning of a pitcher's career, when good pitching mechanics and good pitching habits can be developed (Andrews and Fleisig, 1998). However 'good' pitching mechanics at various levels have not been documented, as all previous studies have been limited to small samples ($n < 30$) of elite adult pitchers (Barrentine et al., 1998; Dillman et al., 1993; Elliott et al., 1986; Feltner et al., 1986; Fleisig et al., 1995,1996; MacWilliams et al., 1998; Pappas et al., 1985,1995; Sakurai et al., 1993; Vaughn, 1985; Werner et al., 1993). Although only adult pitchers were studied, results from these publications have been used as a basis for teaching mechanics to pitchers of all ages. If kinematic differences exist between pitchers of various levels, than teaching younger pitchers based upon data from adult pitchers may be inappropriate. Kinetic differences may be insightful for understanding injury potential. The purpose of this study was to compare pitching biomechanics among various levels of competition.

2. Methods

A sample of 231 healthy male baseball pitchers was analyzed. Included were 23 youth (age range: 10–15 yr, height: 1.67 ± 0.09 m, mass: 55 ± 10 kg), 33 high school (15–20 yr, 1.83 ± 0.07 m, 76 ± 10 kg), 115 college

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(17–23 yr, 1.84 ± 0.05 m, 82 ± 9 kg), and 60 professional (20–29 yr, 1.87 ± 0.08 m, 90 ± 9 kg) level athletes.

After providing informed consent, history, and physical information, each pitcher was tested in an indoor laboratory with a procedure previously described (Escamilla et al., 1998; Fleisig et al., 1996). Reflective markers were attached to 14 bony landmarks. After stretching and warming up, the subject threw ten fastball pitches from a portable pitching mound toward a strike zone ribbon located over a home plate. The distance between the pitching mound to home plate was set equal to the regulation pitching distance for the subject's league (i.e. 18.4 m for high school, college, and professional subjects, and 12–16 m for youth subjects). Ball velocity was measured with a radar gun.

Three-dimensional coordinates were determined with a four-camera 200 Hz automatic digitizing system (Motion Analysis Corporation, Santa Rosa, CA) for the subject's three fastest pitches that hit within the strike zone ribbon. Root mean-square error in calculating marker location was 1.0 cm (Fleisig et al., 1996). Marker position data were filtered with a 13.4 Hz low-pass filter (Fleisig et al., 1996). In each time frame, the locations of the throwing shoulder joint center and the throwing elbow joint center were calculated (Dillman et al., 1993).

Stride length was calculated as the distance between the lead ankle and pitching rubber, expressed as a percentage of the subject's height. Shoulder, elbow, knee, and trunk angular displacements were calculated as described by Fleisig et al. (1996). For each angular displacement measurement, the corresponding velocity was calculated using the 5-point central difference method (Miller and Nelson, 1973). Angular velocities of the pelvis and upper torso were calculated using a method described by Feltner and Dapena (1989).

Using inverse dynamics, shoulder kinetic parameters were calculated as the force and torque applied by the trunk to the upper arm (Fleisig et al., 1995). Similarly, elbow kinetics were calculated as the force and torque applied by the upper arm to the forearm (Fleisig et al., 1995).

Sixteen kinematic and eight kinetic parameters were calculated for various instances and phases of the pitching motion shown in Fig. 1. Six temporal variables were also calculated, with the time of foot contact defined as 0% and the time of ball release defined as 100% (Fleisig et al., 1996). Error analysis of 167 pitches thrown by 19 subjects revealed that compared to group variability, intra-subject variability was moderate (typically 70%) for kinetics and small (typically 30%) for kinematics.

Kinematic, kinetic, and temporal data were averaged for the three pitches analyzed of each subject (Fleisig et al., 1995). A one-way Analysis of Variance was conducted for each parameter to identify differences among the four levels (youth, high school, college, and professional). Differences at the $p < 0.05$ and $p < 0.01$ levels are reported. Because of the variability in group size, Fisher's least significance difference test was performed to identify which pairs of competition levels were different ($p < 0.05$).

3. Results

Of the 16 position and velocity parameters tested, six had significant differences among competition levels (Table 1). All 10 parameters that displayed no significant differences were position parameters. None of the six temporal parameters tested showed significant differences (Table 2). Conversely, all eight kinetic parameters showed significant differences (Table 3).

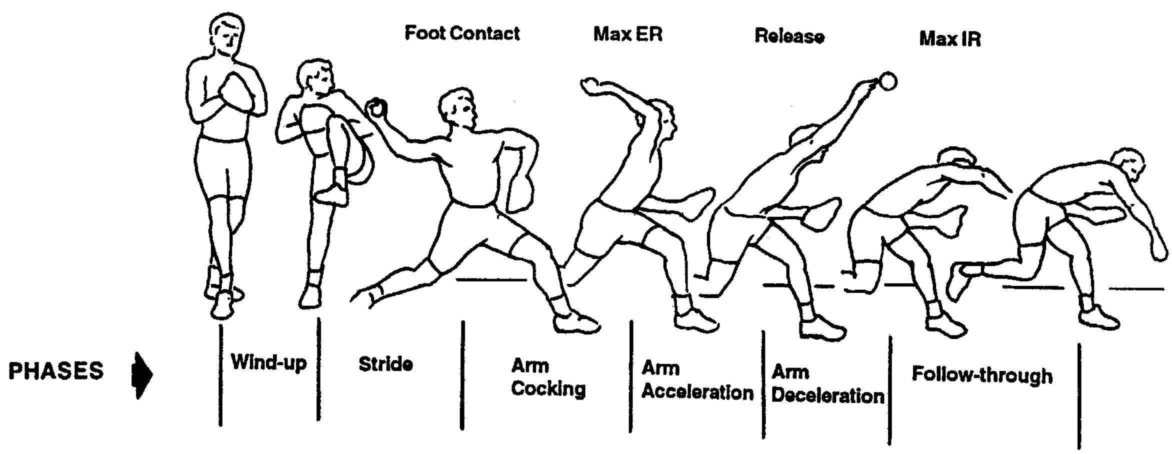

Fig. 1. The six phases of throwing: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. Images represent the instances separating the phases: initial motion, balance point, foot contact, maximum shoulder external rotation (MaxER), release, maximum shoulder internal rotation (MaxIR), and fielding position. (Modified with permission from Fleisig et al., 1996.)

Table 1
Kinematic differences among levels

	Youth ($n = 23$)	High school ($n = 33$)	College ($n = 115$)	Professional ($n = 60$)	Significant differences
Front foot contact					
Stride length (% height)	85 ± 8	85 ± 9	85 ± 6	86 ± 5	
External rotation (°)	67 ± 28	64 ± 25	55 ± 29	58 ± 26	
Elbow flexion (°)	74 ± 17	82 ± 17	85 ± 18	87 ± 15	*(b,c)
Knee flexion (°)	43 ± 12	50 ± 9	48 ± 12	46 ± 8	
Arm cocking phase					
Maximum pelvis velocity (°/s)	650 ± 110	640 ± 90	670 ± 90	620 ± 80	**(f)
Maximum upper torso velocity (°/s)	1180 ± 110	1130 ± 110	1190 ± 100	1200 ± 80	**(a,d,e)
Maximum elbow flexion (°)	95 ± 12	100 ± 14	99 ± 15	98 ± 15	
Maximum horizontal adduction (°)	21 ± 8	20 ± 9	20 ± 8	17 ± 9	
Maximum external rotation (°)	177 ± 12	174 ± 9	173 ± 10	175 ± 11	
Arm acceleration phase					
Maximum elbow extension velocity (°/s)	2230 ± 300	2180 ± 340	2380 ± 300	2320 ± 300	**(b,d,e)
Maximum internal rotation velocity (°/s)	6900 ± 1050	6820 ± 1380	7430 ± 1270	7240 ± 1090	*(d)
Ball release					
Elbow flexion (°)	24 ± 7	23 ± 7	23 ± 6	23 ± 5	
Horizontal adduction (°)	11 ± 9	10 ± 8	9 ± 9	9 ± 10	
Trunk tilt (°)	32 ± 9	31 ± 9	33 ± 10	33 ± 9	
Knee flexion (°)	36 ± 11	43 ± 13	39 ± 13	38 ± 13	
Ball speed (m/s)	28 ± 1	33 ± 2	35 ± 2	37 ± 2	**(a,b,c,d,e,f)

Notes: Significant differences ($p < 0.05$) between (a) youth and high school, (b) youth and college, (c) youth and professional, (d) high school and college, (e) high school and professional, and (f) college and professional.
*Significant differences ($p < 0.05$) among four levels.
**Significant differences ($p < 0.01$) among four levels.

Table 2
Temporal differences among levels. Values measured from front foot contact until particular event, expressed in time (s) or percentage of pitch (where 0% corresponds to the instant of foot contact and 100% corresponds to the instant of ball release)

	Youth ($n = 23$)	High school ($n = 33$)	College ($n = 115$)	Professional ($n = 60$)	Significant differences
Maximum pelvis angular velocity (%pitch)	37 ± 16	39 ± 20	34 ± 18	34 ± 14	
Maximum upper torso angular velocity (%pitch)	49 ± 11	50 ± 11	51 ± 11	52 ± 7	
Maximum external rotation (%pitch)	80 ± 6	81 ± 5	81 ± 5	81 ± 5	
Maximum elbow angular velocity (%pitch)	92 ± 3	91 ± 3	91 ± 5	91 ± 4	
Ball release (s)	0.150 ± 0.025	0.150 ± 0.020	0.145 ± 0.020	0.145 ± 0.015	
Max. internal rotation angular velocity (%pitch)	103 ± 2	102 ± 3	102 ± 5	102 ± 4	

Note: No significant differences ($p < 0.05$) found.

4. Discussion

Of the six kinematic parameters with significant differences, five were velocity parameters and only one was a position parameter. In fact, 16 of the 17 position and temporal parameters presented in Tables 1 and 2 showed no significant differences. Thus, pitching mechanics did not change significantly with level. Rather, the results support the common coaching philosophy that a child should be taught 'proper' pitching mechanics that could

Table 3
Kinetic differences among levels*

	Youth ($n = 23$)	High school ($n = 33$)	College ($n = 115$)	Professional ($n = 60$)	Significant differences
Arm cocking phase					
Elbow varus torque (Nm)	28 ± 7	48 ± 13	55 ± 12	64 ± 15	**(a,b,c,d,e,f)
Shoulder internal rotation torque (Nm)	30 ± 7	51 ± 13	58 ± 12	68 ± 15	**(a,b,c,d,e,f)
Shoulder anterior force (N)	210 ± 60	290 ± 70	350 ± 70	390 ± 90	**(a,b,c,d,e,f)
Arm acceleration phase					
Elbow flexion torque (Nm)	28 ± 7	45 ± 9	52 ± 11	58 ± 13	**(a,b,c,d,e,f)
Arm deceleration phase					
Elbow proximal force (N)	400 ± 100	630 ± 140	770 ± 120	910 ± 140	**(a,b,c,d,e,f)
Shoulder proximal force (N)	480 ± 100	750 ± 170	910 ± 130	1070 ± 190	**(a,b,c,d,e,f)
Shoulder posterior force (N)	160 ± 70	280 ± 100	350 ± 160	390 ± 240	**(a,b,c,d,e)
Shoulder horizontal abduction torque (Nm)	40 ± 14	69 ± 25	89 ± 49	109 ± 85	**(b,c,e,f)

Notes: Significant differences ($p < 0.05$) between (a) youth and high school, (b) youth and college, (c) youth and professional, (d) high school and college, (e) high school and professional, and (f) college and professional.
*Significant differences ($p < 0.05$) among four levels.
**Significant differences ($p < 0.01$) among four levels.

be used throughout a career (International Baseball Foundation, 1996).

Joint forces and torques increased with each level of competition. Since position and temporal differences were not observed, kinetic differences were most likely due to greater muscle strength at each higher level. The greater shoulder and elbow angular velocities produced by higher level pitchers were most likely due to the greater joint forces and torques generated during the arm cocking and acceleration phases. The combination of more arm angular velocity and longer arm segments resulted in greater linear ball velocity for the adult pitcher.

While many features of the game (e.g., field dimensions, bat weight) are scaled down for younger players, standard adult baseballs are used at all levels. The use of a lighter baseball may allow youth league pitchers to generate arm velocities more similar to those produced by adult pitchers, even though youth pitchers produce significantly less force and torque. Also, a ball with a smaller diameter might allow the young pitcher to learn proper grips. Research with smaller, lighter baseballs would be helpful.

Because joint kinetics increased with level of competition, a higher level pitcher may be more susceptible to arm injury. However, such relationships can only be discussed in theory, as joint kinetic values represent the combination of forces in muscles, tendons, ligaments, and bone that connect adjacent body segments. Furthermore, the magnitude of force needed to produce injury most likely varies among levels of competition, due to differences in muscle mass and tissue strength.

Although increased kinetics cannot be proven to increase the risk of injury, interpretation of the data with knowledge of functional anatomy can be insightful. For example, elbow varus torque is produced by tension in the ulnar collateral ligament, tension in the flexor–pronator muscle mass, and compression in the radiocapitellar joint (Feltner and Dapena, 1986; Fleisig et al., 1995). Thus, greater varus torque generated by college and professional pitchers (Table 3) may imply that they are at higher risk for ulnar collateral ligament tear, muscle strain, avascular necrosis, osteochondritis dissecans, or osteochondral chip fractures. Furthermore, the combination of varus torque and elbow extension may lead to osteophyte production at the posterior and posteromedial aspect of the olecranon tip, which can cause chondromalacia and loose body formation (Atwater, 1979; Fleisig et al., 1995). Greater elbow varus torque (Table 3) and elbow extension velocity (Table 1) generated by the higher level pitcher may imply a greater risk for this 'valgus extension overload'.

At the shoulder, large forces are generated throughout the pitch to produce motion and maintain joint stability. The increased shoulder anterior and posterior forces with competition level may correspond with greater shear forces within the glenohumeral joint. Thus, the risk of glenoid labrum injury may increase with level of competition (Fleisig et al., 1995; McLeod and Andrews, 1986). Labrum injury may also occur from the combination of humeral translation, compression, and internal rotation (McLeod and Andrews, 1986; Fleisig et al., 1995). Higher level pitchers may have a greater risk of this 'grinding' injury, since they showed greater shoulder anterior force

(Table 3), proximal force (Table 3), and internal rotation velocity (Table 1).

Rotator cuff injury often results from tensile failure, as the rotator cuff muscles contract to resist distraction, horizontal adduction, and internal rotation of the shoulder during arm deceleration (Andrews and Angelo, 1988; Fleisig et al., 1995). Since the higher level pitcher produced greater shoulder proximal force and shoulder horizontal abduction torque during the arm deceleration phase (Table 3), he likely has a greater risk of rotator cuff injury.

Another shoulder injury is what Snyder et al. (1990) defined as a 'SLAP lesion'. A SLAP lesion occurs in a thrower's shoulder when the long head of the biceps brachii tears the biceps labrum complex from the glenoid rim (Andrews et al., 1985). The biceps is most active in pitching during the arm deceleration phase (DiGiovine, 1992), as the biceps produces both elbow flexion torque and shoulder proximal force to decelerate the throwing arm (Fleisig et al., 1995). The greater magnitudes of elbow flexion torque and shoulder proximal force in the higher level pitcher (Table 3) may require greater contractile force of the long head of the biceps, increasing the chance of a SLAP lesion.

In conclusion, the combination of kinetic differences with a lack of position and temporal differences among competition levels suggests that a pitcher should learn proper mechanics as early as possible, and build strength and fitness as the body matures.

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