0363-5465/101/2929-0137$02.00/0
THE AMERICAN JOURNAL OF SPORTS MEDICINE, Vol. 29, No. 2

The Effects of Extended Play on Professional Baseball Pitchers

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ABSTRACT

The purpose of this study was to investigate kinematic and kinetic changes as a result of extended play in baseball pitching. Seven major league baseball pitchers were videotaped with high-speed (120 Hz) cameras during multiple innings of the same game. For each athlete, two fastballs (one thrown during the initial inning of play and one from the final inning) were chosen for analysis. Twenty-one physical landmarks were manually digitized from the video data. Kinematic and kinetic parameters were subsequently calculated relative to four phases of the pitching motion: windup, cocking, acceleration, and follow-through. Paired *t*-tests revealed that seven parameters changed significantly between early and late innings. These included decreases in maximum external rotation of the shoulder, knee angle at ball release, ball velocity, maximum distraction force at both the shoulder and elbow, and horizontal adduction torque at both release and its maximum value. Ultimately, a decline in performance was evident by a 2 m/s (5 mph) drop in ball speed. It is unclear whether the kinematic and kinetic changes occurred because of fatigue or if protective mechanisms were adopted.

The overhead pitching motion is a highly dynamic movement requiring strength, along with precise timing and coordination of body segments (that is, proper mechanics), to produce accuracy and maximum ball velocity. Ultimately, the success of one pitch is contingent on these elements, and the success of a pitcher over the course of a game is based on his ability to maintain them as the innings progress. Changes due to improper mechanics, poor dynamic stability, or muscle fatigue negatively influence performance and may act to further heighten a pitcher's vulnerability to injury.[4,5]

According to Tom Seaver, in his book *The Art of Pitching*,[25] employing proper mechanics is the secret to pitching mastery and longevity. Consequently, anything that jeopardizes the ability to maintain proper mechanics could potentially have a detrimental effect. Fatigue, over the course of multiple innings, could be a key component to injury potential because of its influence both on the ability of a pitcher to maintain proper mechanics and on the musculature's ability to preserve joint integrity to safely dissipate forces throughout the throwing motion.

Early studies of baseball pitching were descriptive in nature, focusing on understanding and quantifying the kinematics (that is, the motions) involved.[6,7,13,15,24,26] Kinematics is the branch of motion analysis that seeks to describe movement. Displacement, angle, velocity, and acceleration are common variables assessed in kinematic analyses. Kinetics is the branch of motion measurement that seeks to explain the kinematic results. Biomechanical methods allow both direct and indirect assessment of kinetic parameters such as force and torque.

Other throwing studies have considered both kinematic and kinetic variables in an effort to better understand the motion and to relate the act of pitching to possible mechanisms of injury.[14,16–19,27] The shoulder and elbow of the throwing arm have attracted particular interest because of the excessive ranges of motion, high speeds of movement, and the magnitude of loads that these joints experience. Specifically, in relation to the shoulder, kinematic analyses done by Dillman et al.[13] and Fleisig et al.[17] revealed values for external rotation and internal rotation angular velocity in excess of 180 and 7000 deg/sec, respectively. Additionally, Feltner and Dapena,[16] as well as Fleisig et al.,[17] studied kinetic values and reported distraction forces at the time of ball release equal to body

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No author or related institution has received any financial benefit from research in this study.

weight. Concurrently, the elbow may experience distraction forces as high as 780 N and angular accelerations greater than 3000 deg/sec^2, according to studies conducted by Feltner and Dapena[16] and Werner et al.[27]

In regard to the influence of extended play on the pitching motion, Barrentine et al.[9] conducted a study in which game conditions were simulated by having 10 collegiate pitchers throw for multiple innings in a laboratory setting. Several significant changes in kinematics were noted with extended play (increased shoulder abduction, horizontal adduction, and external rotation), all at the instant of stride foot contact. At ball release, less shoulder abduction (dropped elbow) and a straighter lead leg were noticed over the course of multiple innings—two criteria often observed by pitching coaches to indicate fatigue. The study by Barrentine and colleagues was the first to examine the effects of extended periods of throwing, an indirect measurement of fatigue, but it did not seek to correlate the kinematic changes observed with kinetics or injury potential. To the authors' knowledge there have been no scientific attempts to evaluate both the kinematic and kinetic changes that occur with extended bouts of baseball pitching. With this in mind, the current study was designed to analyze the changes in kinematic and kinetic parameters of the baseball pitch that occur over the course of actual major league baseball game conditions.

MATERIALS AND METHODS

Data were collected during actual game play on more than 75 professional pitchers during the 1998 and 1999 Cactus League Spring Training Camps in Arizona. Only those pitchers who pitched a minimum of five innings were considered for this study, creating a subject pool of seven athletes. Five of the pitchers threw for five innings, and the other two pitched for six innings. Mean age, mass, and height parameters for the seven pitchers were 29 ± 6 years, 93 ± 13 kg, and 193 ± 5 cm, respectively. Six of the athletes were right-hand dominant throwers and one was left-hand dominant.

Three high-speed (120 Hz) cameras were employed for data collection. Two of the cameras were positioned along the first and third base lines, typically in both dugouts, providing side views for left- and right-handed pitchers, respectively. A third camera, located in a press box above and behind home plate, provided a frontal view and was used for the analysis of all pitchers (Fig. 1).

A 24-point calibration object (Peak Performance Technologies, Inc., Englewood, Colorado) was videotaped simultaneously by all three cameras, both before and after the game, to calibrate the pitching area. Additionally, horizontal and vertical reference markers were placed on the pitching mound to create a mound-relevant reference

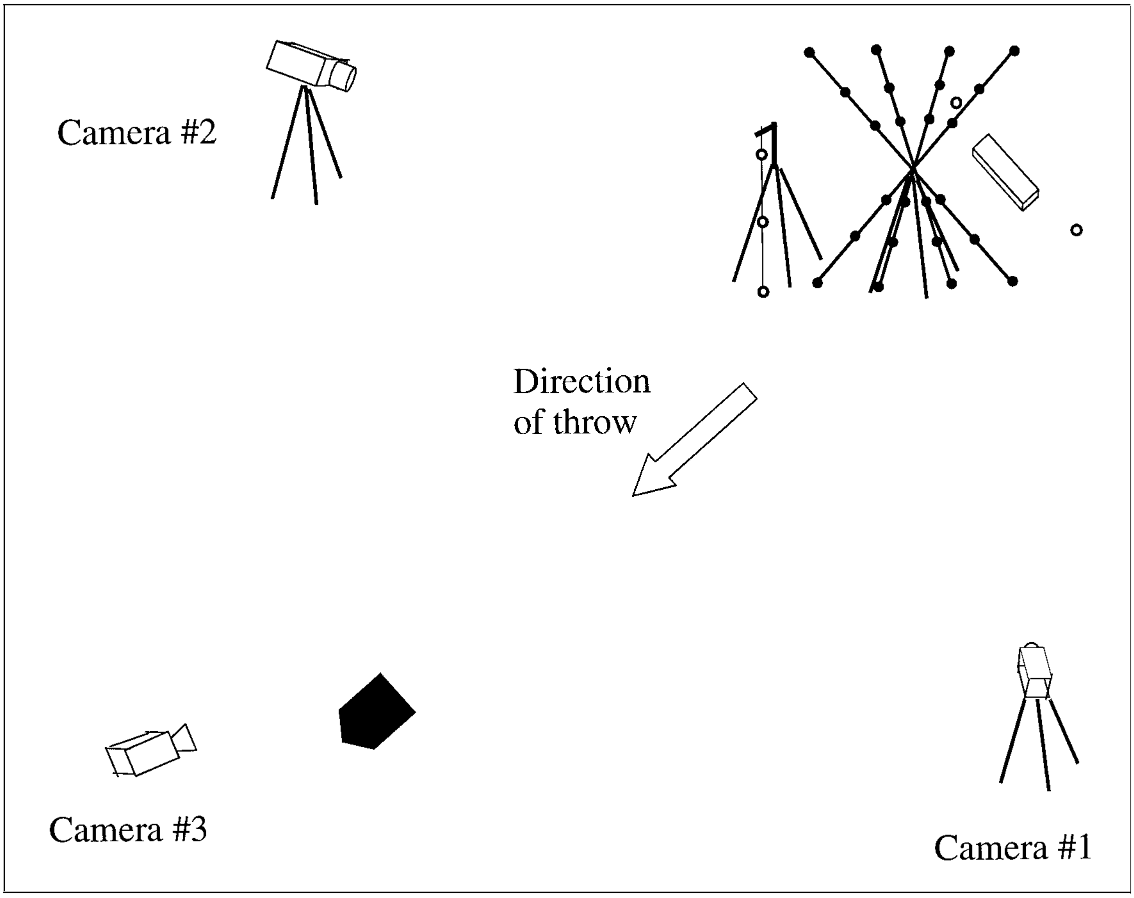

Figure 1. Positions of cameras and markers on the mound used for data collection.

frame (Fig. 1). Data were then collected from the frontal and appropriate side-view cameras for each pitcher throughout his time on the mound. Because data were collected during an actual game situation, the regulation pitching distance of 18.4 meters (60 feet, 6 inches), as well as regulation ball mass and circumference of 0.14 kg and 23 cm (5 ounces and 9 inches), respectively, were used.

For data reduction, a Peak Performance Motus system was used to manually digitize 20 body landmarks and the ball for one fastball from each pitcher's first and last inning of play (Fig. 2). All of the points, with the exceptions of the great toe, heel, and crown of the head, were digitized as approximations of joint centers in each successive frame. In the authors' experience, variability in kinematic and kinetic parameters of successive fastballs is low at an elite level of pitching. Thus, in an effort to reduce the cost (that is, extensive time spent on manual digitization) associated with an aggregate analysis, we assumed that one fastball trial was representative of a pitcher's performance in any one inning of play. The direct linear transformation method was used to obtain three-dimensional coordinate data for the ball and each body landmark. Data from the two cameras were synchronized on the instant of ball release and were conditioned with a Butterworth fourth-order, zero-lag, digital filter with a cutoff frequency of 10 Hz. All coordinate data were expressed in terms of the mound-relevant reference frame.

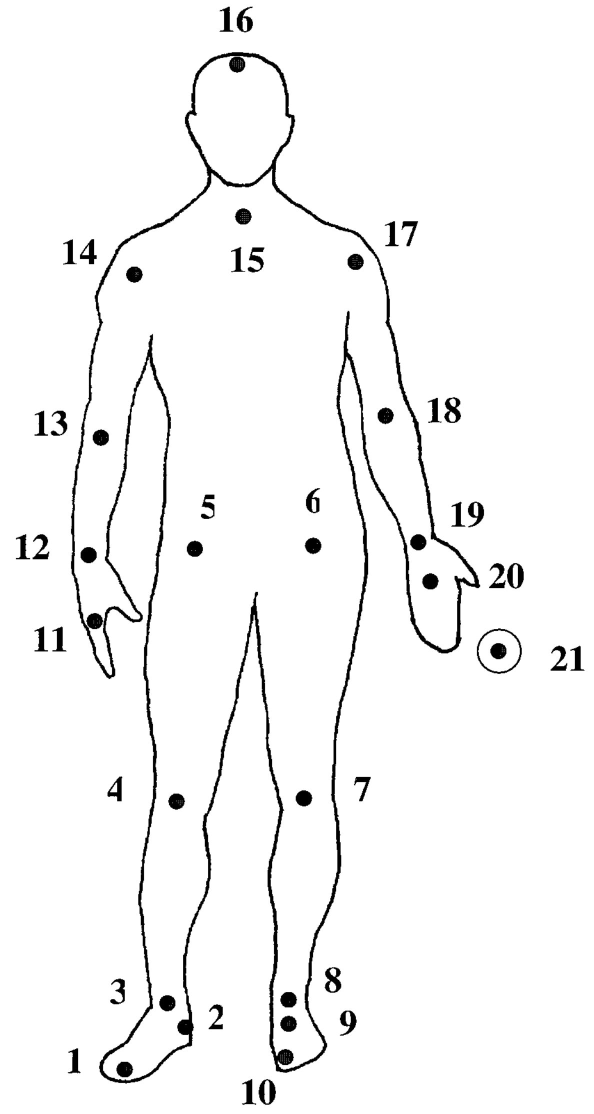

Figure 2. Locations and definitions of the 21 digitized landmarks: 1) right great toe, 2) right ankle, 3) right heel, 4) right knee, 5) right hip, 6) left hip, 7) left knee, 8) left heel, 9) left ankle, 10) left great toe, 11) right third knuckle, 12) right wrist, 13) right elbow, 14) right shoulder, 15) suprasternale, 16) crown of head, 17) left shoulder, 18) left elbow, 19) left wrist, 20) left third knuckle, and 21) the center of the baseball.

Data were subsequently analyzed relative to four phases of the pitching motion: windup, cocking, acceleration, and follow-through (Fig. 3). Windup was defined as beginning with the pitcher's initial movement and ending when the throwing hand and ball were removed from the glove. Cocking was initiated when the ball left the glove and continued until maximum external rotation of the throwing shoulder. The acceleration phase began at maximum external rotation of the shoulder and ended at the instant of ball release. Lastly, the follow-through started at ball release and ended with the pitcher in a ready fielding position. Specifically, we studied the interval from 50 msec before the instant the ball left the glove until 500 msec after ball release.

Figure 4 depicts the convention for measuring shoulder rotation. With the shoulder abducted 90° and the elbow flexed 90°, 0° of rotation indicated that the shoulder was internally rotated with the palm facing the ground. At 180° the shoulder was externally rotated with the palm facing the sky. A knee angle of 180° indicated full extension. Linear velocity and acceleration for the ball and each body landmark were calculated using Peak Motus utilities. Angular velocities were calculated as the first derivative of the time-dependent angular displacements. Shoulder and elbow joint forces and torques were calculated according to methods adapted from Feltner and Dapena[16] and expressed in terms of anatomically relevant elbow and shoulder joint reference frames. To facilitate comparisons between subjects, forces were expressed as a percentage of body weight and torques as a percentage of the product of body weight and height.

Using a standard statistical software package (Systat, SPSS, Inc., Chicago, Illinois), we determined product-moment correlation coefficients between all of the calculated kinematic and kinetic variables. All possible noncorrelated ($r \leq 0.70$) combinations of the kinematic and kinetic measures were assessed to reach an optimal set of 13 parameters: ball velocity, peak shoulder angular velocity, peak external rotation angle of the shoulder, knee angle of the stride leg at the instant of ball release, trunk tilt angle above the horizontal at release, shoulder abduction torque at the instant of maximum external shoulder rotation, shoulder horizontal abduction torque at the instant of ball release, peak elbow distraction force, peak elbow valgus torque, peak shoulder distraction force, peak shoulder

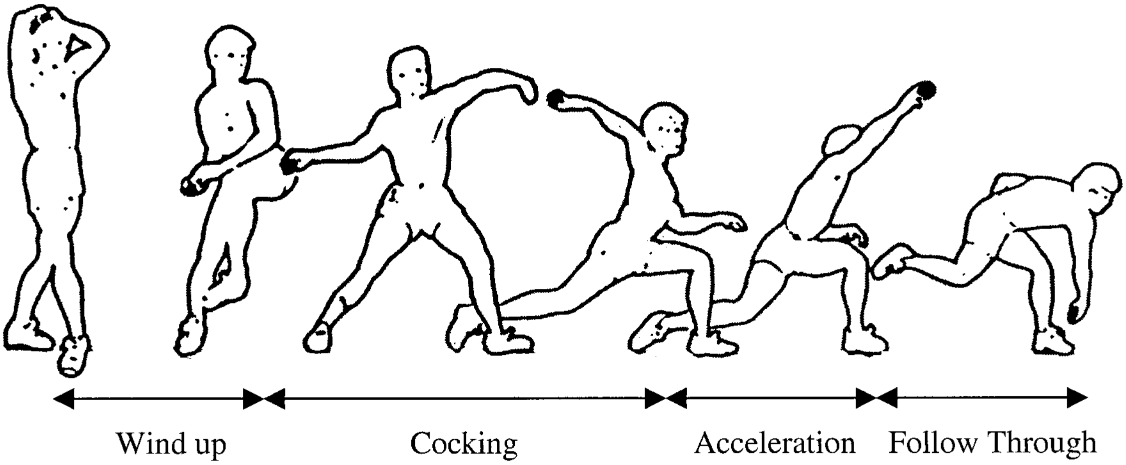

Figure 3. Phases of the baseball pitch (adapted from DiGiovine et al.[12]).

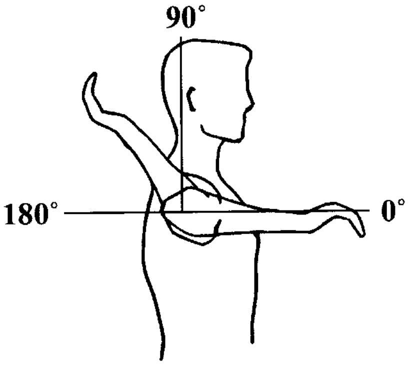

Figure 4. Convention for measuring shoulder internal and external rotation.

horizontal abduction torque, peak shoulder external rotation torque, and peak internal shoulder rotation angular velocity. These parameters were chosen for comparative analysis between early and late innings. Bonferroni-adjusted paired *t*-tests were used to assess significant differences for the 13 kinematic and kinetic variables. The level of significance was set at $P \leq 0.05$.

RESULTS

Paired *t*-test analysis revealed that 7 of the 13 parameters analyzed during the pitch changed significantly between the early and late innings (Table 1). Significant kinematic variables included maximum external rotation angle of the shoulder, knee angle at ball release, and ball velocity. Significant kinetic variables included maximum distraction forces at the shoulder and elbow joints, as well as the horizontal abduction torque at both the instant of ball release and at its peak amplitude. All seven of the parameters decreased significantly in magnitude over the course of the game.

It was during the late cocking phase that the shoulder reached a position of maximum external rotation. In the later innings the pitchers demonstrated decreased external rotation as compared with the earlier innings. On average, a decrement of 9° was noted as a result of extended play. The angle at the knee joint as the ball was released also changed significantly over the course of a game. An average knee angle of 140° was noted in the first inning, with a decrease to 132° by the last inning. Thus, it appeared that the pitcher flexed the stride leg more over the course of the game.

TABLE 1
Significant Kinematic and Kinetic Parameters

Parameter[a]	First inning	Last inning	*P* value
Ball velocity (mph)	90 (40m/s)	85 (38m/s)	0.009
Maximum external rotation of the shoulder (deg)	181	172	0.007
Knee angle at ball release (deg)	140	132	0.024
Maximum shoulder distraction force (% WGT)	97	88	0.018
Maximum elbow distraction force (% WGT)	85	72	0.030
Horizontal abduction torque at ball release (% WGT·HGT)	5	4	0.005
Maximum horizontal abduction torque (% WGT·HGT)	11	8	0.018

[a] % WGT, percent body weight. % WGT·HGT, percent body weight times height.

Shoulder distraction forces peaked near ball release and approached magnitudes of 100% body weight. On average, peak shoulder distraction dropped from a maximum of 97% body weight in the early innings to 88% in the late innings. Distraction forces at the elbow were also large in magnitude and decreased significantly with extended play. Maximum elbow distraction occurred near the instant of ball release and averaged 85% body weight in the first inning and only 72% in the last inning.

Both the horizontal abduction torque at ball release and the peak horizontal abduction torque, which occurred near ball release, decreased significantly over the course of a game. This torque rapidly changed its direction from maximum external shoulder rotation through ball release. The horizontal abduction torque found at ball release decreased from an average of 5 N·m in the first inning to 4 N·m in the last inning. Peak horizontal abduction torque averaged 105 N·m in the early frame as compared with 88 N·m in the final frame. This torque indicated an attempt to control the rapid horizontal adduction occurring at the shoulder joint during the acceleration and follow-through phases.

The final parameter to decrease significantly with extended play was ball speed. On average, pitches were delivered at 40 m/s (90 mph) in the early inning and declined an average of 2 m/s (5 mph) over the course of a game. Since fastball pitches were chosen for analysis, this finding represented a decrement in performance.

DISCUSSION

It is unclear whether the significant changes in pitching mechanics were a direct result of fatigue that occurs with extended play or if the body adopted protective mechanisms to minimize the risk of injury over the course of a game. In the fatigue scenario, it can be suggested that the pitcher could not preserve the original or ideal range of motion and timing patterns of the pitch. Thus, decreased ranges of motion at the shoulder and knee joints were related to the drop in ball velocity and ultimately resulted in less stress at the shoulder and elbow (that is, fatigue yielded a natural decline in kinematic and kinetic variables).

The significantly greater degree of knee flexion at ball release found over the course of a game may indicate muscle fatigue. In turn, less energy may be transferred from the ground to the trunk, subsequently decreasing the amount of energy in the throwing arm. As a result, ball velocity diminishes and joint loads decrease. Likewise, the significant decrease in shoulder external rotation could be a partial explanation for the performance and force decrements found with extended play. Pappas et al.[23] stated that ball velocity would decrease if the shoulder could not achieve the required degree of horizontal adduction or external rotation at the end of the cocking phase. The current study supports this contention.

In contrast, inherent kinematic and kinetic changes may have been the result of the body seeking an optimization strategy to reduce the destructive forces found at the shoulder and elbow. Pappas et al.[23] stated that during extreme external rotation, the glenohumeral joint yields "tight wringing" of the anterior capsule, which subsequently leads to micro- or macroinjury and capsular irritation. Hence, a reduction in the degree of external rotation may imply that the body sought to reduce the risk of injury.

Shoulder distraction has been associated with glenoid labrum and rotator cuff pathologic lesions.[3,6,10,11,17] McLeod and Andrews[22] reported that the labrum is at risk of being entrapped and possibly torn between the humeral head and glenoid rim because of translation and subluxation of the humeral head in the anterior or posterior direction while the shoulder joint is in distraction. As the number of pitches increased over the course of a game, decreased shoulder distraction may be an unconscious attempt to decrease the loads at the joint, the result of imposed kinematic changes (that is, increased ranges of elbow flexion and horizontal adduction at release), or a combination of both. Regardless of the mechanism, the decline of both shoulder and elbow distraction with extended play is most likely a positive change, as less force should reduce the risk of injury to the surrounding structures of the joints.

The significant decrease in horizontal abduction torque with extended play may also be an attempt to limit destructive loads, and thus injury potential. Extreme magnitudes of horizontal abduction torque have been associated with osteophytes, glenoid labrum tears, and straining of the posterior rotator cuff.[2,8,10–12,21] The reduction of this torque may or may not have altered kinematic patterns; however, the risk of injury was most likely diminished.

Shoulder and elbow symptoms prevent 50% of all professional pitchers from throwing at some time in their career.[20] It is hoped that continued research in this area will lead to a better understanding of the effects of extended play and its relationship to injury. With an estimated 4.8 million children between the ages of 5 and 14 playing baseball and softball in the United States each year,[1] coaches and athletes at all levels of play will benefit from a better understanding of the kinematic and kinetic changes in pitching that occur with extended play.

CONCLUSIONS

An investigation into the effects of extended play in professional baseball pitchers revealed significant kinematic and kinetic changes over the course of five to six innings. Decreases in ranges of motion at the shoulder and knee joints were noted. The extent of shoulder external rotation was less in the later innings as compared with the earlier innings, and less knee extension was detected at ball release over the course of a game. Forces and torques at the shoulder and elbow joints also declined with extended play. Ultimately, a decrement in performance was evident by the 2 m/s (5 mph) average drop in ball velocity. It is unclear whether extended play, and subsequent fatigue, results in decreased ranges of motion and speeds of movement, thereby decreasing joint loads and performance, or if, in an attempt to decrease the potential for injury, that certain kinematic and kinetic parameters are decreased and thus lead to a decrement in performance.

ACKNOWLEDGMENTS

The authors acknowledge Mike Decker, MS, Cindy Suplizio, MS, and Andrew Girvan of the Steadman-Hawkins Sports Medicine Foundation; Mike Keirns, PT, PhD, of the Steadman-Hawkins Clinic; Steve McCaw, PhD, of the University of Northern Illinois; and the Major League Baseball Cactus League division for their support in data collection and processing.

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