

Rochelle L. Nicholls^{1,2}, Glenn S. Fleisig¹, Bruce C. Elliott², Stephen L. Lyman¹, E. David Osinski³

¹American Sports Medicine Institute (Birmingham, Alabama, USA); ²University of Western Australia (Perth, Western Australia, Australia); ³American Baseball Foundation (Birmingham, Alabama, USA).

Correct biomechanics minimise the risk of injury and improve performance during baseball pitching. The mechanics of 20 youth pitchers were analysed during outdoor practice using digital camcorders and a checklist of kinematic and temporal elements. The pitchers were also analysed indoors with a six-camera 240Hz Motion Analysis System. In both conditions, mechanics were graded using accepted norms for youth pitchers. Kappa coefficients were calculated between the qualitative measurements and motion analysis data for 17 kinematic parameters. 11 variables showed acceptable relationships between qualitative and quantitative data, indicating the practical value of this qualitative analysis as a field tool.

KEY WORDS: technical analysis, accuracy, injury, performance, coaching

Baseball pitching is one of the most dynamic and stressful of sporting actions. Proper transfer of force from the lower extremities to the throwing arm is vital in generating maximum velocity with appropriate control (Wang et al., 1995), decreasing joint loads and delaying the onset of fatigue (Escamilla et al., 1998; Fleisig et al., 1996).

Three-dimensional computer analysis has been used to quantify the pitching motion (Elliott et al., 1986; Escamilla et al., 1998; Feltner & Dapena, 1986). Detailed information on potential injury mechanisms has been obtained (Dillman, Fleisig & Andrews, 1993; Fleisig et al., 1996), as well as kinematic, temporal and kinetic data for pitchers at various levels of development (Fleisig et al., 1999). Dillman, Fleisig & Andrews (1993) divided the pitch into six phases:

a) Windup: (Figure 1A,B): commences with the initiation of motion and concludes with peak hip flexion in the stride leg. It is a period of low joint forces and torques.

b) Stride: (Figure 1C-E): the lower segments of the body accelerate and decelerate sequentially to transfer energy to the trunk.

c) Arm cocking: (Figure 1F-G): from foot contact, the upper trunk is rotated to face the hitter and maximum external rotation (MER) of the pitching arm is achieved (160-185 deg).

d) Arm acceleration: (Figure 1G-H): humeral internal rotation (6940+/-1080 deg/sec) and elbow extension (2200+/-750 deg/sec) propel the ball to its release point.

e) Arm deceleration: (Figure 1I-J): humeral internal rotation angular velocity decreases from maximum (3-4 msec after BR) to zero through eccentric activation of the rotator cuff and elbow flexors (Fleisig et al., 1996).

f) Follow-through: (Figure 1K): the excess kinetic energy of the arm is absorbed by the posterior shoulder and large muscles of trunk and legs as the pitcher prepares to field.

Quantitative analysis allows objective measurement of the parameters of human performance. Outcomes are based on mechanical principles and yield detailed kinetic and kinematic data. However computer-aided analysis can be expensive and inaccessible to coaches and therapists. Qualitative analysis is the systematic observation of performance

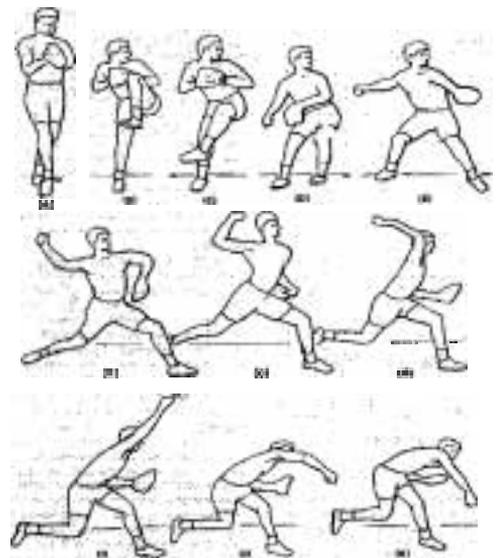


Figure 1 -Phases of baseball pitching

and identification of flaws through rational inspection. Qualitative analysis can be conducted with minimal equipment in almost any setting, and has been used to assess the quality of pitching mechanics through subjective rating scales (Albright et al., 1978). In the absence of high-speed motion analysis, it is important that a qualitative measurement tool provide accurate and reproducible outcomes, particularly in rapid skilled movements such as baseball pitching.

The purpose of this study was to investigate if observation of pitching with a qualitative checklist of mechanics yielded information compatible with that of a three-dimensional biomechanical analysis.

METHODS: Informed consent was obtained from 20 healthy male pitchers (17 right-handed, 3 left-handed). The mean age of subjects was 12.86 +/- 1.29 years, their height was 1.63 +/- 0.13 m, and body mass 53.11 +/- 14.16 kg.

Qualitative analysis: Three digital camcorders mounted on tripods were used to film subjects pitching to a catcher at pre-season training. Cameras were placed behind home-plate, behind the mound, and at 90 degrees to the pitching rubber on the pitcher's open side (third base right-handed pitchers, first base left-handed). Pitch velocity was recorded using a radar gun positioned behind home-plate. After warmup, three pitches were filmed and analysed by the American Baseball Foundation (ABF), a recognised coach and player education body. The analysis was conducted using a 24-item checklist of mechanics, developed using biomechanical data from 52 healthy youth pitchers (Fleisig et al., 1999).

Quantitative analysis: Three-dimensional analysis was completed as soon as possible after qualitative filming (mean 13 +/- 6 days). Testing was undertaken in an indoor laboratory using an artificial youth pitching mound (0.16 m height). Reflective markers were attached to 14 bony landmarks. Subjects threw 10 fastballs to a strike-zone ribbon positioned over home-plate at league regulation distance. Pitch velocity was recorded using the same radar gun. Marker locations were tracked and auto-digitised by the Motion Analysis System (Motion Analysis Inc., Santa Rosa, CA) utilising six calibrated 240 Hz cameras and a protocol previously described (Escamilla et al., 1998). The three fastest trials to hit the ribbon were analysed. Data was filtered using a second-order low-pass Butterworth filter (6 Hz). Kinematic and temporal data were calculated from the instant the stride foot contacted the mound until 30 msec after ball release, as the highest segment velocities and forces occur during this time (Dillman, Fleisig & Andrews, 1993).

Data analysis: Twenty-four kinematic parameters were subjectively rated for each pitcher as Low, Correct or High using the qualitative checklist. The parameters were:

1. Preparation: windup (WU), balance (B), hand separation (HS), stride hip path (SHP)
2. Instant of foot contact: stride length (SL)*, stride offset (SO)*, foot angle (FA)*; humeral horizontal adduction (HA_{FC})*, abduction (AB_{FC})*, external rotation (ER_{FC})*; elbow flexion (EF_{FC})*; knee flexion (KF_{FC})*
3. Arm cocking phase: sequence of hip and shoulder rotation (HSR)*; maximum elbow flexion (MXE)*; maximum humeral external rotation (MER)*, trunk arching (TA)*, glove arm (GA)*
4. Instant of ball release: humeral abduction (AB_{BR})*, horizontal adduction (HA_{BR})*, elbow flexion (EF_{BR})*, trunk flexion (TF_{BR})*, trunk lateral flexion (LTT_{BR})*, knee flexion (KF_{BR})*
5. Follow-through (FT)

Ratings from three trials were averaged to provide a single rating for each variable.

Seventeen variables (indicated *) were quantified in three-dimensional analysis. Kinematic and temporal values were compared to accepted norms for youth pitchers (Fleisig et al., 1999) and converted to ratings of Low, Correct or High using the following criteria:

1. Low: greater than 1 standard deviation below the established mean;
2. Correct: within 1 standard deviation of the established mean;
3. High: greater than 1 standard deviation above the established mean.

Camcorder views were taken from the front, open side and rear during motion analysis. The video was analysed using the checklist to establish intra-rater reliability through comparison

with outdoor results. This second analysis served to qualify any technical changes which may have occurred in the period between outdoor and indoor filming.

Kappa coefficients (k) were used to establish the reproducibility of scores between qualitative and quantitative analysis, and qualitative-indoor and qualitative-outdoor. The analysis was conducted using 2x2 contingency tables between proper and improper (high or low) mechanics, proper and low mechanics, and proper and high mechanics. The kappa coefficient grades agreement between conditions as (<0.00) unacceptable, (0.00-0.40) marginal, (0.40-0.75) good, (0.75-1.00) excellent (Rosner, 1995). Significance was set at $p < 0.05$, where p indicates whether the finding is significantly different to that expected by chance ($k=0.00$).

RESULTS:

Table 1 Kappa Coefficients between Qualitative and Quantitative Analysis:

Event	Variable	Proper1 improper	Proper1 low	Proper1 high
Foot contact	Stride length (SL)	0.45	0.51*	n.a.
	Knee flexion (KF _{FC})	0.29	0.21	n.a.
	Stride offset (SO)	-0.05	n.a.	0.11
	Foot angle (FA)	0.15	n.a.	0.63*
	Horizontal adduction (HA _{FC})	0.27	-0.22	1.00**
	External rotation (ER _{FC})	0.31	1.00**	0.16
	Abduction (AB _{FC})	-0.10	0.44	-0.17
	Elbow flexion (EF _{FC})	0.80**	1.00**	0.74**
Arm cocking1 acceleration	Hiplshoulder rotation (HSR)	0.42*	n.a.	0.52**
	Maximum elbow flexion (MXE)	-0.18	0.12	-0.08
	Maximum external rotation (MER)	0.29	0.42	n.a.
Ball release	Knee flexion (KF _{BR})	0.13	n.a.	-0.21
	Lateral trunk tilt (LTT _{BR})	0.31	0.39	0.19
	Trunk flexion (TF _{BR})	0.67**	-0.12	n.a.
	Horizontal adduction (HA _{BR})	0.41*	-0.07	0.38
	Abduction (AB _{BR})	0.32	0.42	n.a.
	Elbow flexion (EF _{BR})	0.21	0.19	0.44*

* $p < 0.05$, ** $p < 0.01$

n/a = no qualitative result recorded for any subject

Nine qualitative variables reproduced the findings of the motion analysis (Table 1): SL, FA, HA_{FC}, ER_{FC}, EF_{FC}, HSR, TF_{BR}, HA_{BR}, EF_{BR}. Remarkable, if not statistically significant, results were also evident for AB_{FC} ($k=0.44$, $p=0.057$) and LTT_{BR} ($k=0.39$, $p=0.051$).

When the qualitative field analysis and indoor qualitative analysis were compared, all 24 variables in the checklist yielded kappa coefficients (for proper/improper mechanics) from 0.40 to 0.90, with 22 significant at $p < 0.05$ and 10 significant at $p < 0.01$. This indicates the pitchers' mechanics did not significantly change in the 13 +/- 6 days between sessions and were not affected by pitching in the indoor environment. It also indicates acceptable intra-rater reliability.

DISCUSSION: Qualitative assessment was comparable with motion analysis for eleven variables in their ability to detect correct, low or high baseball pitching mechanics. These variables were well distributed throughout the phases of pitching in which highest joint forces and torques are evident, indicating a good ability to detect mechanics at critical instants such as foot contact and ball release.

Equipment constraints may have limited the accuracy of the checklist in detecting further variables, particularly those occurring through the acceleration phase of pitching. The frame

rate of a digital camcorder is 30 frames/second. Humeral internal rotation during the acceleration phase can exceed 7000 deg/sec and is one of the fastest human motions (Dillman, Fleisig and Andrews, 1993) – therefore camcorders may not be sensitive enough to quantify variables occurring during this phase. Filming and analysing a greater number of trials for each pitcher may increase the likelihood of an extremely fast event being captured at 30 fps, and hence true maximums be identified.

The inherent dangers of bias, human error and subjectivity cannot be completely eliminated from qualitative analysis protocols. This study controlled for such confounding factors analysing each subject on two occasions (field and indoor) using the checklist to establish the repeatability of the rater's analysis. The rater was blind to the results of the motion analysis and participation history of each subject. A further study is planned to investigate the role of an observer's experience in detecting mechanics accurately, using multiple trials and multiple raters.

Observation of pitching with a qualitative checklist of mechanics yielded information compatible with that of a three-dimensional biomechanical analysis, indicating value as a field tool. The analysis requires only a camcorder, can be undertaken in almost any setting, and is simple to complete, with three choices listed for each variable (Figure 2).



Elbow flexion at foot contact:

- The throwing elbow is flexed to approximately 90 degrees as the lead foot contacts the mound (*PROPER*)
- The throwing elbow is flexed toward the pitcher's head (*LOW*)
- The throwing elbow is too straight (*HIGH*)

Figure 2 - Example from qualitative checklist of mechanics

CONCLUSION: A simple checklist of parameters relevant to successful pitching has been developed. The checklist is based on published biomechanical data and relationships obtained between field and laboratory test results of 20 youth pitchers. The checklist provides a scientific method for coaches and therapists to assess the quality of mechanics with regard to prevention of injury, and enhancement of velocity and control.

REFERENCES:

- Albright, J.A., Jokl, P., Shaw, R., Albright, J.P. (1978) Clinical study of baseball pitchers: correlation of injury to the throwing arm with method of delivery. *The American Journal of Sports Medicine* 6:1, 15-21.
- Dillman, C.J., Fleisig, G.S., Andrews, J.R. (1993) Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic and Sports Physical Therapy* 18:2, 402-408.
- Elliott, B., Grove, J.R., Gibson, P., Thurston, B. (1986) A three-dimensional cinematographic analysis of the fastball and curveball pitches in baseball. *International Journal of Sport Biomechanics* 2:1, 20-28.
- Escamilla, R.F., Fleisig, G.S., Barrentine, S.W., Zheng, N., Andrews, J.R. (1998) Kinematic comparison of throwing different type of baseball pitches *Journal of Applied Biomechanics* 14:1-23
- Feltner, M., Dapena, J. (1986) Dynamics of the shoulder and elbow joints of the throwing arm during a baseball pitch. *International Journal of Sport Biomechanics* 2: 235-259.
- Fleisig, G.S., Barrentine, S.W., Escamilla, R.F., Andrews, J.R. (1996) Biomechanics of overhand throwing with implications for injuries. *Sports Medicine* 6:421-437.
- Fleisig, G.S., Barrentine, S.W., Zheng, N., Escamilla, R.F., Andrews, J.R. (1999) Baseball pitching at various levels of development. *Accepted: Journal of Biomechanics*.
- Rosner, B (1995) *Fundamentals of Biostatistics*, Fourth Edition; Wadsworth Publishing Company.
- Wang, Y., Ford, H.T. III, Ford, H.T. jnr, Shin, D.M. (1995) Three-dimensional kinematic analysis of baseball pitching in acceleration phase. *Perceptual and Motor Skills* 80: 43-48.