DIFFERENCES AMONG THE OVERHAND, THREE-QUARTER, SIDEARM AND UNDERHAND DELIVERY STYLES IN BASEBALL PITCHERS

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The aim of the study was to clarify the biomechanical differences among the overhand (OS), three-quarter (TS), sidearm (SS) and underhand (US) styles of baseball pitching. About 700 pitches were videotaped using the 3D DLT method. The fastest pitch of each pitcher was used to establish criteria for the separation of the pitches into the four styles based on coaches' observation and on trunk lateral tilt and upper arm elevation angles. Forty-nine pitches were selected for analysis, and classified into 18 OS, 10 TS, 10 SS and 11 US deliveries. Twenty-six kinematic and kinetic variables were calculated and analyzed. Trunk lateral tilt and upper arm elevation angles were significantly larger in the order OS-TS-SS-US. Ball velocity was significantly slower in the US group than in the other three. Significant differences were found among the groups in six kinematic and five kinetic variables. The slow ball velocity in the US group may have been causally linked to the significantly smaller forces and torques of the US group in relation to the other three.

KEYWORDS: quantitative classification, shoulder and elbow, kinematics and kinetics.

INTRODUCTION: Baseball pitches are generally classified into four delivery styles based upon the visually identified release position of the throwing arm in a global reference system: overhand (OS), three-quarter (TS), sidearm (SS) and underhand (US) styles (Nolan & Torre, 1977). Since a three-dimensional (3D) quantitative study regarding the dynamics of the shoulder and elbow joints in baseball pitching was reported by Feltner and Dapena (1986), a number of studies have been conducted, including studies of movement mechanisms, performance improvement, injury generation and prevention, and growth and development. However, most of these studies focused on the overhand pitching (or throwing) style. Recently, Escamilla et al. (2018) analyzed the kinematic and kinetic differences among the OS, TS and SS delivery styles in professional baseball pitchers, and reported that most significant differences occurred between the OS and SS groups. No study has compared the kinematic and kinetic differences among the four delivery styles with the addition of the underhand style. If the differences between the pitching styles were better known, this information could be used to improve pitching technique in the various styles from the perspectives of performance enhancement and injury risk reduction.
The purpose of this study was to clarify the kinematic and kinetic differences of the throwing shoulder and elbow joints among the OS, TS, SS and US styles. Two hypotheses were set for the study: (1) ball velocity at release is smaller in the order OS-TS-SS-US; and (2) there are significant kinematic and kinetic differences between the four style groups, with the largest differences occurring between the OS and US groups.

METHODS: Seventy male amateur baseball pitchers (mean ± SD: age 19.3 ± 2.2 years; standing height 1.75 ± 0.05 m; body mass 72.4 ± 7.0 kg; throwing experience 11.4 ± 3.0 years), including 3 post-collegiate, 55 collegiate and 12 high school pitchers, participated in this study. Experiments were performed on the pitching mound of a baseball stadium. After a warm-up that included throwing, each pitcher made about 10 fastball pitches at maximum effort toward the catcher. Three of the pitchers had used more than one style for their standard fastball pitching in games in the course of their careers, and thus were allowed to use those styles in the experiment. Sufficient rest for full recovery was allowed between trials. All pitches were videotaped with two high-speed video cameras (GC-LJ20B, JVC, Japan) at 240 frames/s. For each pitcher, the fastest trial in which the ball was judged a strike was selected for the establishment of normative data for each style based on observation by seven highly experienced coaches and on trunk tilt and throwing arm elevation angles at ball release. Two-dimensional coordinates of 21 body landmarks and the ball center were manually digitized in each camera using a video motion analysis system (Frame-DIAS V, DKH, Japan). The 3D body landmark and ball coordinates were calculated using the direct linear transformation (DLT) method, and then smoothed using quintic spline functions with optimal cutoff frequencies. The pitches were quantitatively classified into OS, TS, SS and US styles in accordance with Miyanishi et al. (2020).

Mahalanobis area calculations (Sakurai & Ohtsuki, 2000) were used to establish 90% confidence distribution ranges of trunk lateral tilt and upper arm elevation angles for each pitching style. The four elliptical areas overlapped to some extent. Forty-nine pitches that fell within the 90% confidence areas but outside the overlaps (18 OS, 10 TS, 10 SS and 11 US) were selected for subsequent analysis.

Joint angles and torques for abduction-adduction, horizontal abduction-adduction and internal-external rotation of the throwing shoulder and flexion-extension of the throwing elbow, and also joint forces for anteroposterior, superoinferior and proximodistal forces of the shoulder and anteroposterior, mediolateral and proximodistal forces of the elbow were calculated throughout the pitches using custom-made FORTRAN programs based on Feltner and Dapena (1986).

A one-way analysis of variance (ANOVA, unpaired) was performed to assess differences in the physical characteristics of the four groups, including age, standing height, body mass and years of throwing experience, and also 15 kinematic and 11 kinetic variables. (See Tables 1 and 2, which include the abbreviations of the parameter names.) If a significant main effect was found, pairwise comparisons were performed using student *t* tests with a Bonferroni correction. Significance levels were set at $p < .05$, $p < .01$ and $p < .001$ for each test. All statistical analyses were performed using SPSS version 25 (SPSS Inc., Chicago, IL).

RESULTS: No significant differences were found in the physical characteristics of the four groups. Significant differences were found in the ball velocity between the US group and the other three groups (Table 1). Significant differences were found in the trunk lateral tilt and upper arm elevation angles between all four groups. They were larger in the order OS-TS-SS-US (Table 1).

Table 2 shows the selected 15 kinematic and 11 kinetic variables for the throwing shoulder and elbow joints. Significant differences were found in six kinematic variables: shoulder horizontal-abduction angle at stride foot contact (SFC); shoulder abduction, shoulder horizontal-adduction and elbow extension angles at maximum shoulder external rotation (MER); shoulder abduction and shoulder external-rotation angles at ball release (REL), and in five kinetic variables: maximum shoulder anterior and shoulder superior forces in arm cocking phase (ACP); maximum shoulder internal-rotation and elbow varus torques and maximum elbow medial force near the instant of maximum external rotation (nMER).

Table 1: Comparisons of ball velocity and angles for trunk lateral tilt and upper arm elevation (Mean (SD)) among the four groups.

Variables [Units]	**OS** (n=18)	**TS** (n=10)	**SS** (n=10)	**US** (n=11)	Significant differences†
Ball velocity [ms^{-1}]	35.4 (1.6)	35.4 (1.9)	34.8 (1.2)	31.8 (1.9)	***(c)(e),**(f)
Trunk lateral tilt [deg]	32 (4)	17 (7)	-1 (8)	-39 (19)	***(b)(c)(e)(f),**(a)(d)
Upper arm elevation [deg]	42 (6)	21 (8)	-4 (4)	-40 (11)	***(a)(b)(c)(d)(e)(f)

[Notes] Unit [deg] indicates segment angle.
† Significant differences between (a) OS and TS, (b) OS and SS, (c) OS and US, (d) TS and SS, (e) TS and US, (f) SS and US.
Significant differences: *$p < .05$; **$p < .01$; ***$p < .001$.

Table 2: Comparisons of the selected variables (Mean (SD)) among the four groups.

Variables [Units]	**OS** (n=18)	**TS** (n=10)	**SS** (n=10)	**US** (n=11)	Significant differences†
At the instant of stride foot contact (SFC)					
Shoulder Abduction [deg]	78 (12)	78 (9)	73 (12)	83 (8)	
Shoulder Horizontal-Abduction [deg]	19 (12)	18 (8)	14 (8)	7 (5)	*(c)
Shoulder Internal-Rotation [deg]	22 (35)	26 (22)	16 (18)	12 (26)	
Elbow Extension [deg]	67 (10)	76 (12)	75 (12)	79 (16)	
Arm cocking phase (ACP)					
Max.Shoulder Horizontal-Adduction [Nm]	82 (20)	71 (14)	77 (18)	67 (16)	
Max.Elbow Extension [Nm]	23 (14)	16 (10)	20 (7)	24 (10)	
Max.Shoulder Anterior [N]	276 (76)	269 (41)	271 (84)	203 (60)	*(c)
Max.Shoulder Superior [N]	322 (87)	216 (59)	280 (90)	228 (74)	**(a),*(c)
Near the instant of maximum shoulder external rotation (nMER)					
Max.Shoulder Abduction [Nm]	78 (20)	57 (14)	67 (27)	60 (24)	
Max.Shoulder Internal-Rotation [Nm]	95 (21)	84 (16)	83 (22)	70 (12)	**(c)
Max.Elbow Varus [Nm]	96 (21)	85 (16)	85 (22)	71 (13)	**(c)
Max.Elbow Medial [N]	352 (68)	299 (62)	317 (87)	262 (49)	**(c)
At the instant of maximum shoulder external rotation (MER)					
Shoulder Abduction [deg]	111 (7)	104 (6)	101 (9)	103 (10)	*(b)
Shoulder Horizontal-Adduction [deg]	1 (7)	3 (5)	3 (8)	9 (8)	*(c)
Max.Shoulder External-Rotation [deg]	101 (9)	96 (8)	105 (8)	102 (10)	
Elbow Extension [deg]	93 (14)	97 (15)	95 (10)	110 (21)	*(c)
Near the instant of ball release (nREL)					
Max.Elbow Flexion [Nm]	15 (6)	18 (8)	22 (9)	16 (7)	
Max.Shoulder Proximal [N]	858 (176)	873 (121)	929 (180)	800 (138)	
Max.Elbow Proximal [N]	880 (133)	834 (92)	910 (184)	765 (124)	
At the instant of ball release (REL)					
Shoulder Abduction [deg]	115 (6)	111 (8)	107 (10)	106 (7)	*(c)
Shoulder Horizontal-Adduction [deg]	0 (7)	2 (4)	2 (10)	5 (5)	
Shoulder External-Rotation [deg]	37 (18)	32 (24)	36 (27)	8 (22)	**(c),*(f)
Elbow Extension [deg]	160 (6)	158 (5)	160 (7)	163 (6)	

[Notes] Unit [deg] indicates joint angle; Unit [Nm] joint torque; Unit [N] joint force, Max.: maximum.
† Significant differences between (a) OS and TS, (b) OS and SS, (c) OS and US, (f) SS and US.

DISCUSSION: Significant differences in the trunk lateral tilt and upper arm elevation angles were found between all pitch groups (Table 1). This confirmed the results of the study of Miyanishi et al. (2020) that the pitching motion could be classified into the four delivery styles by the motions of trunk lateral tilt and upper arm elevation.

Our results partially supported the first hypothesis. Although there was no significant difference in the ball velocity between groups OS, TS and SS, the US group had the lowest ball velocity compared with the other three groups (Table 1). The lack of difference in ball velocity between groups OS, TS and SS was consistent with the results of the study by Escamilla et al. (2018). Our results also partially supported the second hypothesis. There were many differences between the OS and US groups: 10 significant differences out of 23 kinematic and kinetic variables (Table 2). However, there were no significant differences between the OS, TS and SS groups nor between the US group and the TS and SS groups, except for 3 variables: the maximum shoulder superior force in the arm cocking phase between OS and TS; the shoulder abduction angle at maximum shoulder external rotation between OS and SS; and the shoulder external-rotation angle at ball release between SS and US (Table 2). This contrasted with the results of Escamilla et al. (2018), who found that, out of 37 kinematic and kinetic variables analyzed, there were significant differences in 13 between OS and SS, 11 between TS and SS, and 4 between OS and TS. These discrepancies may be due to the use of different criteria to classify delivery styles, or to differences in the participants used (professional vs. amateur). In what follows, we will focus mainly on why the US group had a slower ball velocity than the other groups.

According to previous studies, some selected variables for highly skilled pitchers (including professional and Olympian) who were able to produce large ball velocities included larger shoulder anterior and shoulder superior forces in the arm cocking phase (Fleisig et al., 1999; Escamilla et al., 2001, 2002) and larger shoulder internal-rotation and maximum elbow varus torques near maximum external rotation (Fleisig et al., 1999; Escamilla et al., 2002). Of these variables, Feltner and Dapena (1986) reported that generating larger shoulder anterior and shoulder superior forces in the arm cocking phase is associated with the generation of a larger shoulder external-rotation angle at maximum external rotation, and larger shoulder internal-rotation and elbow varus torques near maximum external rotation. Therefore, the shoulder anterior and shoulder superior force productions in the arm cocking phase, which were smallest in the US, seem to have led to lower shoulder internal-rotation and elbow varus torques near maximum external rotation. This may have resulted in the US having the slowest ball velocity.

It is also interesting that the maximum shoulder horizontal-adduction, shoulder abduction, shoulder internal-rotation, and elbow varus torques were larger in the OS group than in the TS and SS groups, even though there was no significant difference in ball velocity among the three groups. This implied that the OS group may be less effective than the other groups in the sense that it requires a greater loading of the arm to achieve the same ball speed. To assess this, it would be necessary to investigate the angular momentum of the whole-body system throughout the pitching cycle.

CONCLUSION: This study compared the kinematic and kinetic differences among four delivery styles of baseball pitching based upon the quantitative classification of each style. Significant differences in the selected kinematic and kinetic variables were mostly found between the overhand and underhand groups. There were fewer significant differences in the variables among overhand, three-quarter and sidearm groups. Further investigation would be necessary to clarify the biomechanical characteristics for the four pitching styles from the perspectives of performance enhancement and injury prevention.

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