CLASSIFICATION OF FOUR DELIVERY STYLES OF PITCHING MOTON IN YOUNG BASEBALL PLAYERS

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The purpose of this study was to examine the release positions of the throwing arm and of the trunk in four delivery styles (overarm, three-quarter arm, sidearm and underarm) of the baseball pitching motion, and to identify criteria to define the four delivery styles based on the positions of both the trunk and throwing arm (upper arm) segments. Motions of 34 pitchers were videotaped using the 3D DLT method. These motions were qualitatively classified by coaches' observation into 15 overarm, 7 three-quarter arm, 7 sidearm and 5 underarm deliveries. The angles for the trunk lateral tilt and upper arm elevation in the global coordinate system were quantified, and regression analysis revealed a linear relationship between the two angles. Criteria based on these angles were developed that matched the coaches' observations well, demonstrating that the baseball pitching motion could be quantitatively classified into the four delivery styles.

KEYWORDS: trunk lateral tilt, upper arm elevation, 3D video analysis

INTRODUCTION: Before recommending a delivery style for the baseball pitching motion of a player, it is important to have a better understanding of the various delivery styles. The baseball pitching motion is generally classified into four styles based on the release position of the throwing arm in the global reference frame: overarm (OS), three-quarter arm (TS), sidearm (SS) and underarm (US) styles, as indicated in Figure 1 (Miyanishi & Morimoto, 2007). Atwater (1979) pointed out that, regardless of the style used, in most throwing skills the upper arm is abducted almost 90° from the upper trunk, and fully extended at the elbow at or near release. Thus, she suggested that the release position of the throwing arm relative to a global reference frame was determined by the trunk lateral tilt in the frontal plane rather than by the shoulder joint angle. According to this, the delivery styles of the baseball pitching motion are determined primarily by the position of the upper trunk relative to the global reference frame rather than that of the throwing arm relative to the trunk.

Some attempts have been made to clarify the kinematic differences among the overarm, three-quarter, and sidearm delivery styles of the pitching motion in professional pitchers (Matsuo et al., 2000; Escamilla et al., 2018), but there are no quantitative studies of the trunk tilt and of the position of the throwing arm at release associated with the four delivery styles in young pitchers.

The purpose of this study was to examine the tilt of the trunk and the position of the throwing arm at release in the four delivery styles of the baseball pitching motion, and to identify criteria to define the four delivery styles based on the positions of both the trunk and the throwing arm segments. It was hypothesized that the release position of the throwing arm for each delivery style of the pitching motion

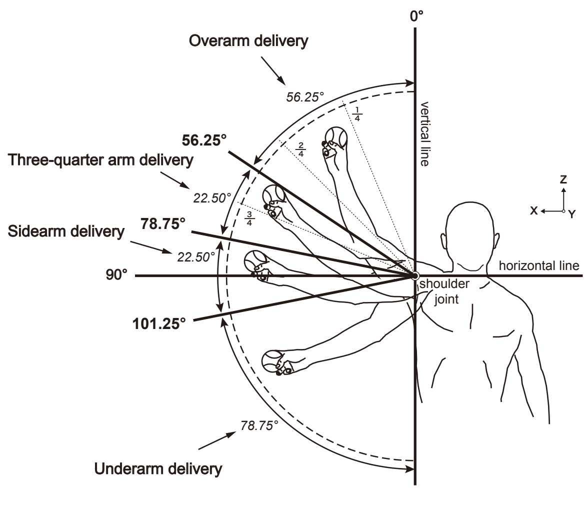

Figure 1: Classification of the four delivery styles of the pitching motion (Miyanishi & Morimoto, 2007, partially modified).

could be determined by the position of the trunk relative to the global reference frame rather than the position of the throwing arm relative to the trunk.

METHODS: Thirty-four right-handed young male baseball pitchers (mean ± SD: age 19.1 ± 1.6 years, range = 15-22 years; standing height 1.74 ± 0.06 m; body mass 70.2 ± 6.8 kg; throwing experience 10.7 ± 2.4 years), including 30 collegiate and 4 high school, participated in this study. All of them were healthy, and had no history of arm surgery or present arm pain. The study was approved by the institutional research ethics committee and all participants – or a parent for underage players (less than 20 years) – signed an informed consent form prior to the experiments.

Experiments were performed on the pitching mound of a baseball stadium. After a warm-up that included throwing, each pitcher was asked to throw about 10 fastball pitches at maximum effort toward the catcher. Sufficient rest for full recovery was allowed between trials. All pitches were videotaped with two high-speed CMOS video cameras (GC-LJ20B, JVC, Japan) at 240 frames/s. The fastest trial in which the ball, measured by a radar gun, was judged a strike was selected for analysis. Two-dimensional coordinates of 26 body landmarks (including the ball center) and of the 68 control points of a special control object (Miyanishi, 2017a) recorded with each camera were manually digitized using a Video Motion Analysis System (Frame-DIAS V, DKH, Japan). Image distortion due to the progressive downward scan of the CMOS cameras was corrected taking into account the cameras' blanking period (Miyanishi, 2017b). The 3D body landmark coordinates were calculated using the Direct Linear Transformation (DLT) method (Abdel-Aziz & Karara, 1971), and then smoothed using quintic spline functions (Woltring, 1986) with optimal cutoff frequencies (ranges: 4–24 Hz) for each body landmark coordinate (Winter, 1990).

To identify criteria to define the four delivery styles, two procedures were conducted. First, each pitching motion was qualitatively evaluated by observation of one active and three former head coaches, who separated the pitches into OS, TS, SS and US styles. Second, a trunk segment was defined as a vector pointing from the mid-point of both hip joints to the suprasternale, and a throwing arm segment as a vector pointing from the shoulder joint to the elbow joint (Figure 2). The average angles for the trunk lateral tilt (θ_t) and upper arm elevation (θ_a) in the XZ plane of the global coordinate system at release were calculated using the trunk and upper arm segments, respectively (Figure 2).

Linear regression analysis was used to investigate the relation between θ_t and θ_a. A one-way analysis of variance (ANOVA, unpaired) was used to assess differences among the four groups in physical characteristics including standing height, body mass and years of throwing experience, and also kinematic variables including ball velocity (the first derivative of the ball position data), θ_t, θ_a, the abduction angle of the throwing shoulder (the angle between the trunk and upper arm vectors in the frontal plane of the trunk's local coordinate system), and the extension angle of the throwing elbow (the angle between the upper arm and forearm vectors) at release. A Bonferroni correction was included. 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).

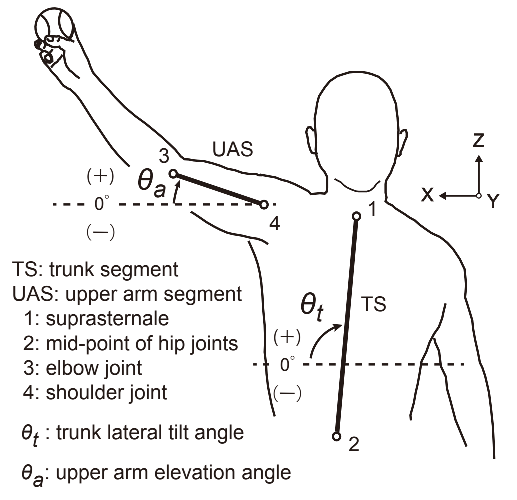

Figure 2: Definitions of the trunk and upper arm segments and of the angles of both segments.

RESULTS: The coaches separated the throws into 15 OS, 7 TS, 7 SS and 5 US. No significant differences were found in standing height, body mass and years of throwing experience among the four delivery groups. Ball velocity at release was 36.3 ± 1.3 $m \cdot s^{-1}$ for OS, 35.1 ± 2.8 $m \cdot s^{-1}$

for TS, 33.3 ± 3.0 m·s^{-1} for SS, and 31.9 ± 1.8 m·s^{-1} for US, respectively. The ball velocity of the OS group was significantly larger than those of the SS ($p < .05$) and US ($p < .01$).
Table 1 shows the angular variables. No significant difference was found in the throwing shoulder abduction and elbow extension angles among the four groups, except for the elbow extension angle between TS and SS. Significant differences were found in the trunk lateral tilt and upper arm elevation angles between all four groups.
Figure 3 shows a scattergram of angles θ_t and θ_a. Linear regression is indicated by the broken straight line. The solid straight line indicates theoretical positions corresponding to a right angle (90°) between the trunk and upper arm segments.
Figure 4 shows the criteria used to define the four delivery groups based on the angles of trunk lateral tilt and upper arm elevation as well as the coaches' observation of the pitching motion.

Table 1: Comparisons of the kinematic variables among the four groups.

	OS	TS	SS	US	Significant differences†
shoulder abduction [deg]	113 ± 7	109 ± 8	107 ± 14	108 ± 4	
elbow extension [deg]	158 ± 6	154 ± 3	163 ± 5	160 ± 8	*(d)
trunk lateral tilt [deg]	122 ± 6	97 ± 4	84 ± 7	48 ± 8	***(a)(b)(c)(e)(f), **(d)
upper arm elevation [deg]	37 ± 9	4 ± 7	- 7 ± 10	- 41 ±10	***(a)(b)(c)(e)(f)

Note: † 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: * $p < .05$; ** $p < .01$; *** $p < .001$.

DISCUSSION: To analyze the relations between θ_t and θ_a in the four groups, the trunk lateral tilt and upper arm elevation angles were quantified (Figure 3). Regression analysis showed a linear relationship between θ_t and θ_a, with a high coefficient of determination, $R^2 = 0.91$. The quantitative angle data also showed good agreement with the coaches' judgment for separation of the throws into the four styles. The trunk lateral tilt and upper arm elevation angles can be used to separate the throws into distinct groups, with only a slight overlap between the SS and TS styles. There are no sharp dividing lines between adjacent groups, but it is possible to establish approximate borders between them. Four delivery groups could be defined based on the values of the two angles (Figure 3) as follows: OS ($\theta_t > 105°$ and $\theta_a > 15°$); TS ($85° < \theta_t < 110°$ and $-10° < \theta_a < 20°$); SS ($65° < \theta_t < 95°$ and $-25° < \theta_a < 10°$); and US ($\theta_t < 70°$ and $\theta_a < -20°$), as shown in Figure 4.
The solid straight line in Figure 3 shows where the dots would need to be for a 90° angle between the trunk and the upper arm. On average, the points were slightly above the line, indicating an average anatomical abduction of slightly more than 90°.

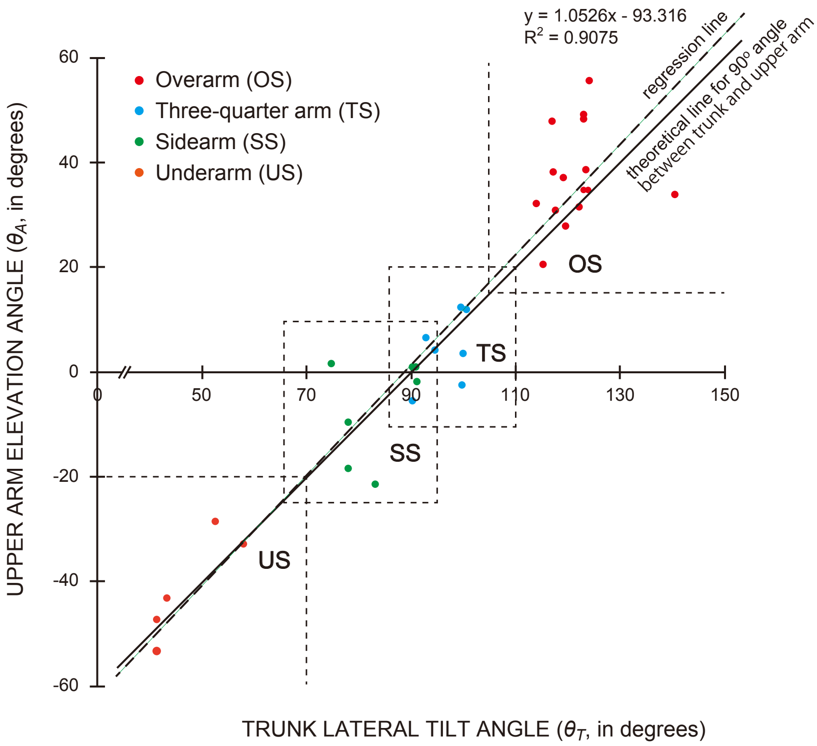

Figure 3: Scattergram of the relation between the trunk lateral tilt and upper arm elevation angles.

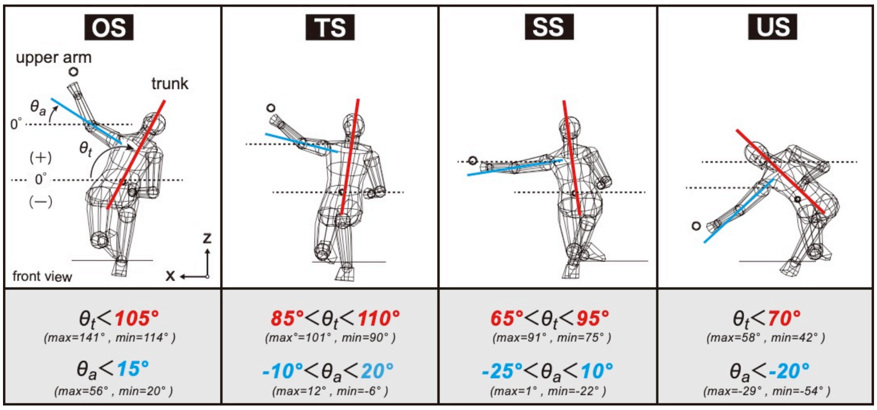

Figure 4: The criteria to define the delivery styles of pitching motion based upon the positions of the trunk and upper arm segments.

We found almost no differences in the anatomical angles of throwing shoulder abduction and elbow extension between the four groups (Table 1). This agreed with Atwater's findings. The results also indicated that the release positions of the four groups were determined mainly by the amount of trunk lateral tilt rather than throwing arm shoulder abduction.
A limitation of the study was the measurement error of the trunk lateral tilt angle due to the trunk segment used in the model. Since we used the whole-trunk segment instead of the upper trunk segment, the amount of trunk lateral tilt away from the vertical was probably underestimated for each delivery style, which probably led to overestimation of the shoulder abduction angle. Another limitation was the small sample size used for each of the delivery styles. These limitations may have affected the interpretation of the results. Future study will be needed to confirm the criteria used in this study to classify the delivery styles.

CONCLUSION: This study measured two global angles (trunk lateral tilt and upper arm elevation) and two joint angles (shoulder abduction and elbow extension) during the arm acceleration phase. The data showed that the four delivery styles differed in the two global angles but not in the two joint angles. Therefore, global upper arm elevation correlated with trunk lateral tilt. Shoulder abduction and elbow extension are similar across pitchers; therefore delivery style is determined by trunk lateral tilt.

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