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Short Communication Open Access

A Preliminary Study to Capture the Characteristics of Backswing Movement in Baseball Throwing

Hiromu Katsumata[1*], Junichiro Sasaki[2] and Takeshi Kawai[3,4]

[1]*Department of Sports and Health Science, Daito-Bunka University, Tokyo, Japan*

[2]*Sendai-Ikuei High School, Miyagi, Japan*

[3]*Faculty of Health and Sports Science, Juntendo University, Tokyo, Japan*

[4]*Musashigaoka College, Saitama, Japan*

[*]**Corresponding author:** Hiromu Katsumata, Department of Sports and Health Science, Daito-Bunka University, Tokyo, Japan, E-mail: hiromu@xd6.so-net.ne.jp

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Movement of baseball pitching is composed of multiple motion phases: a forward arm swing is preceded by a backward swing motion whilst stepping a leading foot in the direction of pitch, transferring the body center of gravity toward the direction of a pitch, and rotating the trunk. Primary focus in many previous studies has been joint kinematics/kinetics in the forward swing phase to investigate the mechanism of delivering a fast pitch [1-4], and the proximal to-distal sequential speed increment of arm segments from shoulder to wrist through elbow has been regarded as the feature of skilled throwing movement. For delivering high speed pitch, backswing movement also plays an important role as a counter movement for utilizing biomechanical properties to accelerating the forward arm swing. In the present study, we attempt to capture the characteristic of backswing movement.

To this end, ten high school baseball pitchers (height: 1.77 ± 0.04 m; weight: 72.9 ± 5.4 kg; age: 17.2 ± 1.0) delivered a ball to the target at their best for fast ball speed. All the participants had played baseball for 7.9 ± 1.1 years at athletic level such that their baseball club has been qualified to national athletic competitions. Preliminary to the experiment, the experimenter explained the experiment's purpose and procedure; each participant signed the informed consent form. The study was conducted by the principles set forth in the Helsinki Declaration and was approved by the appropriate ethics committee.

Three-dimensional coordinates of ball and body landmarks (the centers of wrist and elbow joints of throwing limb, and the centers of left and right shoulder joints and hipbones) were calculated by a motion analysis system (Winanalyze, Mikromak, Germany), and filtered by 4th-order Butterworth with cut-off frequency of 18 Hz. Experimental setup and the definition of a global reference frame were described in Figure 1. For three-dimensional analysis of body and ball movements, position vectors of the body landmarks and ball in terms of the global reference frame was calculated. Velocity and acceleration of the ball and landmarks were obtained by the time derivative of the position vectors.

As Figure 2 shows, the ball speed was different across the participants, ranging from 30 to 40.5 m/s. Speed of 40 m/s can be regarded as very fast to get batters out and 30 m/s as moderately fast. By this diversified level of pitching performance, we attempted to capture the characteristic of backswing movement, which is associated with different ball speeds. Exemplary speed profiles of the ball and

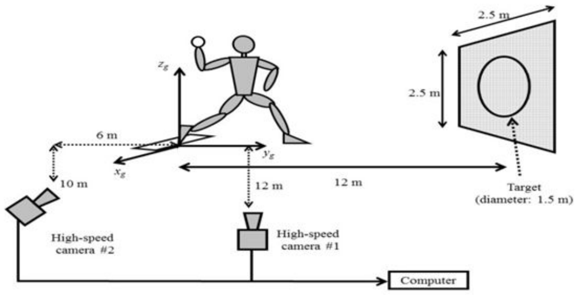

Figure 1: Set up: Ten right-handed participants threw the ball five times with their own pitching styles. None of them had a problem to hit the target in this experiment set up. The movements were recorded (125 Hz) by two high-speed cameras (VFC-1000SB, FOR-A, Tokyo, Japan).

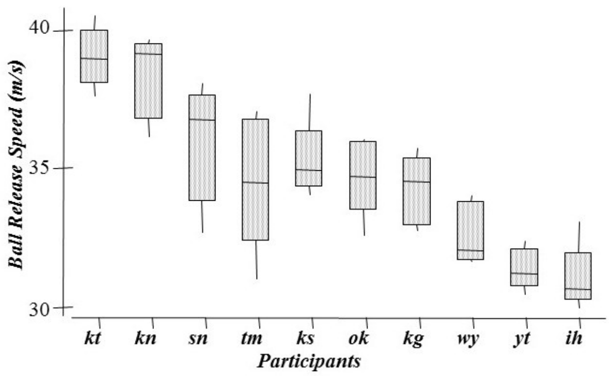

Figure 2: Box plot of the ball release speed for each participant: The mean and standard deviation were 34.7 ± 2.9 m/s.

throwing arm over time were shown on Figure 3 with pitching motion phases. What is notable in Figure 3 is that, prior to the proximal-to-distal sequential speed increment in the forward swing phase, the ball speed increased after the backswing onset and then decreased to the moment of the transition from the backswing to the forward swing movement. To capture this feature of backswing movement in term of the role of counter movement, kinematic landmarks of ball speed and acceleration profiles (Figure 4) were identified. Correlation analysis between those backswing parameters and the forward swing parameters (ball release speed, peak ball acceleration, and peak acceleration and speed of shoulder, elbow and wrist movement (Figures 3 and 4) was conducted and reported in Table 1.

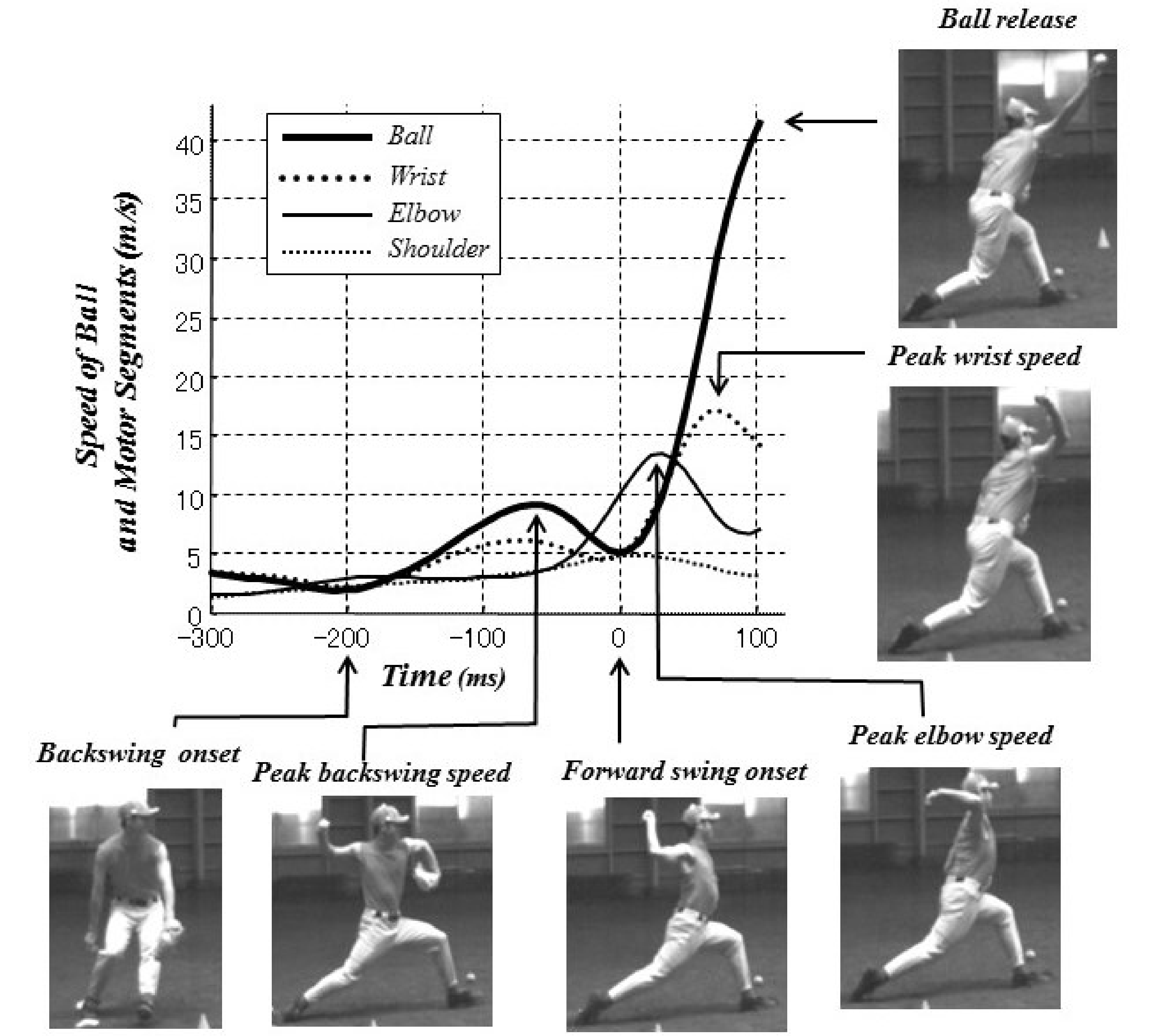

Figure 3: Speed profile of ball and shoulder, elbow and wrist: One exemplary speed profiles of ball and the throwing arm's shoulder, elbow, and wrist over time was plotted. The moment, at which the initiation of abrupt increase in the ball speed to the moment of ball release was defined as the forward swing onset, at which the time was shown as zero. The backswing (i.e., backward arm swing) started after the downward motion of the throwing arm (Backswing onset). In the forward swing phase from the forward swing onset to the ball release, the peak speeds of shoulder, elbow, wrist, and ball revealed sequential increment, which is regarded as the feature of skilled throwing movement.

Significant positive correlation between the peak backswing speed and the peak elbow speed (R=0.65, $p<0.05$) indicates that higher backswing speed was followed by higher elbow speed in the forward swing. This implies that the effect of counter movement may more

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directly influence a proximal segment's movement rather than more distal segments' ones. Since significant positive correlation between the peak elbow speed and the peak wrist speed (refer to the forward swing phase in Figure 3) was obtained (R=0.68, $p<0.05$, not included in the table), higher backswing speed seems to produce higher speed of the forward arm swing. Furthermore, the peak backswing deceleration showed significant negative correlation with the peak ball acceleration (R=-0.86, $p<0.01$) as well as the ball release speed (R=-0.71, $p<0.05$), indicating that the larger magnitude of backswing deceleration was followed by the larger magnitude of ball acceleration in the forward swing and the higher ball release speed.

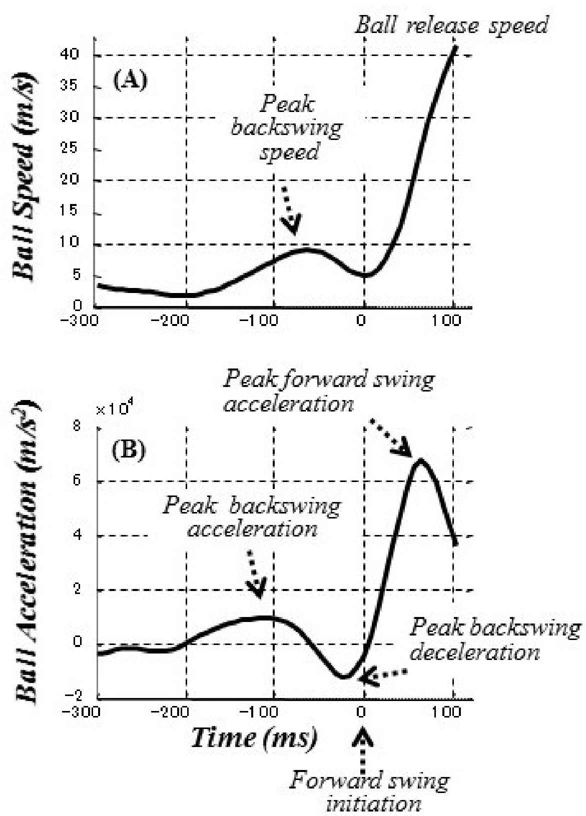

Figure 4: Speed and acceleration profiles of ball: One exemplary profile of speed (A) and acceleration (B) was plotted. For calculating the work applied to the ball, the ball's power was calculated by multiplying the speed and acceleration of the ball at each data point and the mass of the ball. The work applied to the ball in the backswing movement was calculated by the numerical integration of the ball's power over the duration of the speed increase from the backswing onset to the peak ball speed (the backswing positive work) and the duration of the speed decrease from the peak ball speed to the forward swing onset (the backswing negative work), respectively. Work over the duration from the forward swing onset to the ball release was also calculated (the positive work).

The deceleration phase of the backswing movement is a feature of transition from the backswing movement to the initiation of the forward swing, and this transition seems to play a role for producing higher speed of the ball. In the transition from the backswing to the forward swing, the throwing arm and the ball lagged back against trunk rotation due to the inertial resistance of the arm and the ball [2,5]. This inertial effect seems to induce the stretch-shortening cycle of the muscular-tendon system [5,6], and thereby force produced by the subsequent concentric contraction in the forward arm swing can be enhanced. The following correlation analysis supports this inference. The positive backswing work and the negative backswing work showed significant negative correlation (R=-0.76, $p<0.05$).

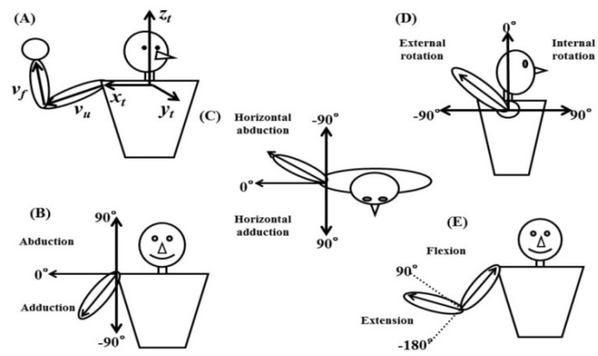

Figure 5: Definition of joint angles: (A) Local reference frame attached to the trunk was defined by direction vectors xt, yt, and zt: xt pointed from the midpoint between right and left shoulders to the right shoulder; yt was determined by the cross product of xt and the vector from the midpoint of two shoulders to the midpoint of two hipbones; zt was defined by the cross product of xt and yt. To describe the upper arm and forearm segments, two vectors Vu and Vf were defined as the vector pointing from the shoulder joint center of the right arm to the elbow joint center of the right arm and the vector pointing from the elbow joint center to the wrist joint center of the right arm respectively. Based on the reference frame, the following joint angles of the throwing arm were calculated. (B) Shoulder abduction/adduction angle: the angle formed by xt and the projection of vu onto the plane determined by xt and zt. (C) Shoulder horizontal abduction/adduction angle: the angle formed by xt and the projection of vu onto the plane determined by xt and yt. (D) Shoulder internal/external rotation angle: the angle formed by the projection of zt and vf onto the plane perpendicular to the longitudinal axis of the upper arm. (E) The flexion/extension angle at the elbow joint: the angle formed by vf and vu. In addition to the arm joint angles, trunk rotation was defined by the angle formed by xg and xt, which was projected on the horizontal plane.

In addition to it, correlations of these positive and negative backswing work with the positive work in the forward swing were significant (R=0.72, $p<0.05$) and marginally significant (R=-0.59, $p=0.07$), respectively. These results imply that producing larger positive work after the initiation of the backswing motion, followed by larger negative work to the moment of the backswing-forward swing transition, was associated with obtaining larger work in the forward swing phase. These characteristics are correspondent with the function of a counter movement such that the negative work during a preparatory movement in a direction opposite to a primary movement can induce the stretch-shortening cycle of muscle group [6] and enhance the positive work in the primary movement [5].

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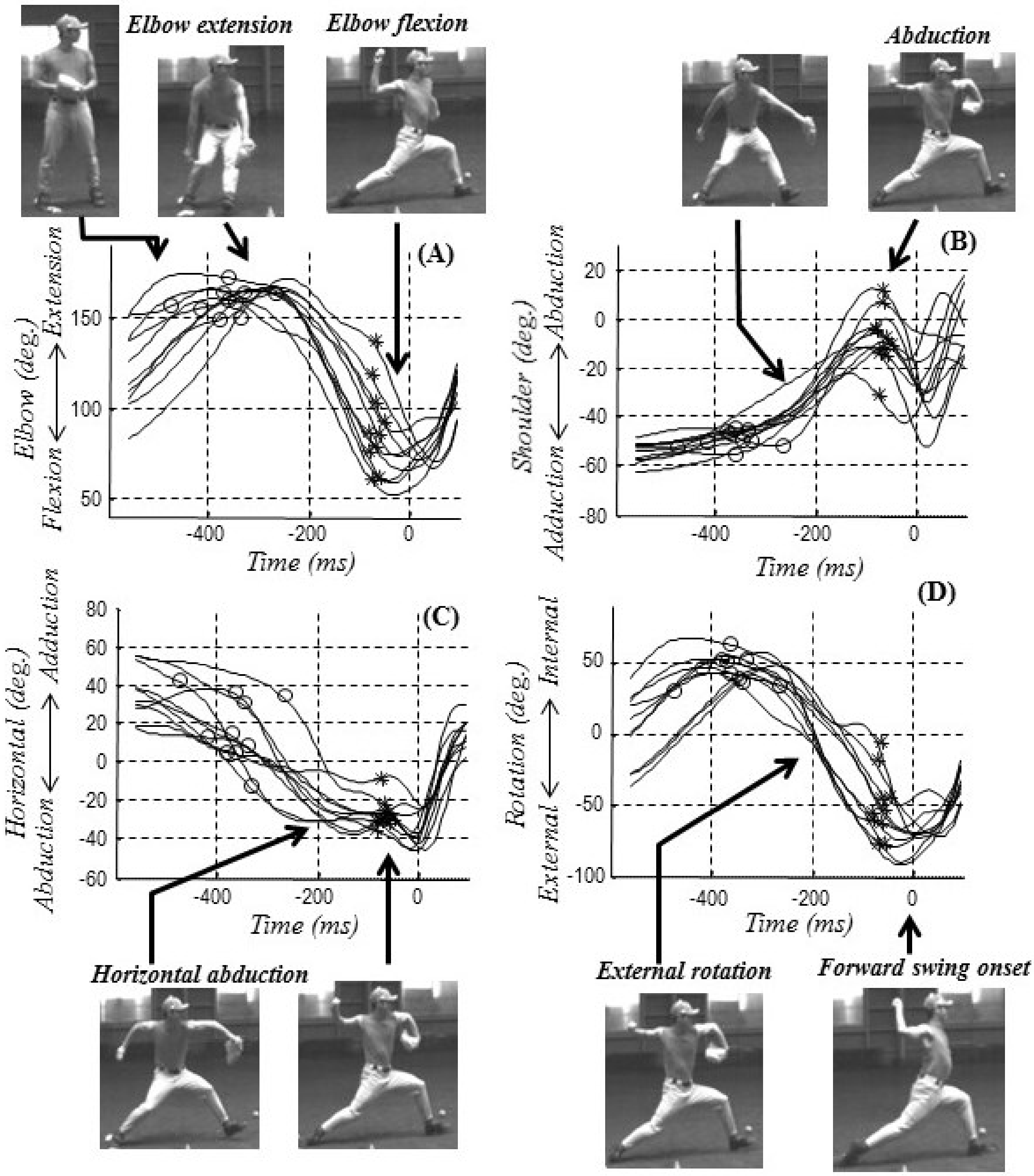

Figure 6: Joint angular excursions of the throwing arm. A: Elbow flexion-extension, B: Shoulder abduction-adduction, C: Shoulder horizontal abduction-adduction, D: Shoulder external-internal rotation, Time zero refers to the moment of the forward swing onset. ○: Backswing onset; *: Peak backswing speed.

To describe the backswing movement of throwing arm, angular excursions of the shoulder and elbow of the throwing arm were calculated based on Feltner and Dapena's study [2], and the definition of those angles were shown in Figure 5. Mean joint angle profile over time for each participant was calculated and superposed on Figure 6. As the figure shows, the backswing arm motion was produced by the internal-to-external rotation, adduction-to-abduction, and horizontal adduction-to-abduction of the shoulder joint with the extension-to-flexion of the elbow. In addition to these arm joint movements, trunk rotated in counter-clockwise direction on the horizontal plane. We attempted to capture how these arm joint movements and the trunk rotation were associated with the characteristic of backswing movement (i.e., Peak backswing speed, acceleration, and deceleration) by correlation analysis between these parameters and the joint movement parameters as shown in Table 2 and reported below. Peak deceleration of elbow flexion showed significant positive correlation with the peak backswing speed (R=0.66, $p<0.05$) and negative correlation with the backswing deceleration (R=-0.79, $p<0.01$). These correlations mean that the higher speed of the backswing movement and the larger magnitude of its deceleration were accompanied by the larger magnitude of acceleration in the direction of elbow extension whilst the elbow was flexed.

These results imply that by the backswing-to-forward swing transition, which is characterized by the abrupt change in the direction of backswing movement, the counter movement can play a role to accelerate the forward swing. The deceleration of elbow flexion seems to reflect this transition from the counter movement to the forward swing, during which the elbow was extended to throw the ball. As another result, peak acceleration of external rotation showed significant negative correlation with the backswing deceleration (R=-0.65, $p<0.05$), indicating that the larger magnitude of accelerating the external rotation, which was in the counter direction to the forward arm swing movement, was associated with the smaller magnitude of the backswing deceleration before its transition to the

Parameters	Peak backswing speed	Peak backswing acceleration	Peak backswing deceleration
Peak elbow acceleration	0.45	0.09	-0.33
Peak elbow speed	0.65*	0.4	-0.01
Peak wrist acceleration	0.25	0.27	-0.42
Peak wrist speed	0.21	0.29	0.28
Peak ball acceleration	0.53	0.36	-0.86**
Ball release speed	0.5	0.56	-0.71*
n=10; **p<0.01; *p<0.05			

Table 1: Pearson correlation coefficients between the backswing and forward swing parameters.

Parameters of joint motion during the backswing	Peak backswing speed	Peak backswing acceleration	Peak backswing deceleration
Elbow flexion			
Peak angular velocity	-0.49	-0.41	**0.58**
Peak angular acceleration	-0.18	0.08	-0.03
Peak angular deceleration	**0.66***	0.58	**-0.79****
Abduction			
Peak angular velocity	0.38	0.23	-0.03
Peak angular acceleration	0.49	0.38	-0.38
Peak angular deceleration	0.02	0.35	-0.08
Horizontal abduction			
Peak angular velocity	-0.22	-0.22	**0.56**
Peak angular acceleration	-0.27	-0.26	0.34
Peak angular deceleration	0.1	0.04	-0.19
External rotation			
Peak angular velocity	0.21	0.31	-0.58
Peak angular acceleration	0.32	**0.59**	**-0.65***
Peak angular deceleration	-0.07	-0.22	0.49
Trunk rotation			
Peak angular velocity	-0.04	-0.17	0.08
Peak angular acceleration	0.3	0.27	-0.59
n=10			
**p<0.01; *p<0.05; Bold numbers: p<0.1			

Table 2: Pearson correlation coefficients between the parameters of joint motion during the backswing and the backswing parameters.

forward swing. This implies a possibility such that, according to the result that the forward swing acceleration and the higher ball speed are associated with the larger backswing deceleration, the external rotation should not be produced in a ballistic way.

Multiple joint movements of a whole body must be organized to throw a ball. Differences in how these multiple motor segments are organized result in different throwing styles. However, a common aim of different throwing styles is to deliver a ball at higher speed. Therefore, we focused on the ball kinematics to investigate the characteristic of backswing movement, based on theoretical frame work such that an end-point effector movement, which is directly related to the aim of task performance, arises from common mechanism for different movement styles [7-9].

Motivated by this perspective, we attempted to identify a kinematic variable that captures the characteristics of a backswing movement and relevant to producing higher pitch speed. By this analysis, the results implied that producing higher ball speed in the backswing and decelerating it abruptly for transition to the forward arm swing movement can contribute to accelerating the forward arm swing and producing higher ball speed. This characteristic of backswing movement reflects effective transition from the backswing movement to the forward swing movement for transferring mechanical energy to the forward swing limb movement. Based on this finding, we could use these key parameters of the ball's backswing kinematics as the window to investigate the arm joint movements for detecting key parameters of backswing arm movement, which is associated with the feature of backswing movement.

For further study, we attempt to adopt this analytical method to investigate large number of participants across different skill levels. Thereby, key parameters of backswing kinematics, which are common or limited to different levels of performance and physical competency, can be identified. Such key parameters can be a clue to assess the quality of performances and to study further the organization of throwing movement by narrowing down the level of analysis to joint kinematics/kinetics to search for an efficient movement pattern. We also expect that identifying key parameters, which can capture an important aspect of task movement, can give us knowledge for evaluating skill level of throwing performance and for designing method to practice throwing. By focusing on change in those parameter values over practice, improvement of performance can be investigated. Likewise, the level of task performance can be assessed in terms of those parameter values. In the case of throwing performances as in the present study, the backswing acceleration/deceleration can be one of the checkpoints for assessing the level of performance and the improvement of pitching skill in terms of the movement organization for delivering a fast pitch. For enhancing motor skill learning, application of task constraints in practice situation is an important aspect [10]. Based on the theory of motor learning, in which learners search for a movement pattern proper to a given set of task constraints [11], searching for a backswing movement pattern associated with the key parameters may lead to obtaining an effective counter movement to accelerate a ball effectively toward the moment of release. Therefore, the findings on backswing movement in the present study can be a clue to provide task constraints, which can be assigned by task instruction, feedback information, contents of practice drill, and direction of attention for guiding learners to search for a solution to achieve a task goal in a practical sports field.

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