Effects of Non-throwing Arm on Trunk and Throwing Arm Movements in Baseball Pitching

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1. Introduction

Increasing throwing velocities is a big challenge for baseball strategy. Mechanics as well as physical strength are important determinants in improving throwing velocities and are often-discussed themes in sports biomechanics.

Though studies on throwing motions often focus on the throwing arm movement, Toyoshima, et al., (1974) reported that contributions of the throwing arm to the throwing velocity was 53.1%, indicating the importance of energy transferred by the trunk rotation. Miyanishi, et al., (1997) conducted a three-dimensional analysis of the throwing motion, showing that the maximum mechanical energy is generated sequentially from the upper torso, upper arm, forearm, hand, and then to the ball. The energy is transferred from proximal to distal segments. Hirashima, et al., (2002) also argued that the trunk muscles become activated prior to the throwing arm muscles, contributing to an increase in throwing velocities. The frontal side of the trunk of a right-handed pitcher faces third base prior to stride phase, then rotates to the left and faces the batter at ball release. Stodden, et al., (2001) analyzed throwing motions of the trunk, by dividing the upper torso and the pelvis. They found that the pelvis is oriented more toward the batter than the upper torso at the instant of stride foot contact on the ground, and that both angles become approximately equal at the instant of the maximum external rotation of the shoulder joint. The upper torso keeps rotating toward the ball release, whereas the pelvis angle remains almost unchanged and the rotation is slowing down. Rotation occurs first in the pelvis and then in the upper torso, causing the trunk to be twisted. This trunk twist will generate stretches in the trunk muscles, which will cause an increase in muscle force by stored elastic energy [Asmussen and Bonde-Petersen, (1974)] and induced stretch reflex [Dietz, et al.,]
The twist will also increase the motion range which cause an increase in mechanical work, presumably leading to higher throwing velocities. Additionally, isometric torque in the axial rotation the trunk was greater when exerted with pre-rotated posture in the reverse direction of rotation, in comparison with that exerted with the neutral posture [Kumar, et al., (2002)]. It is presumed that the length of muscles influences muscle force, so that stretched muscles will exhibit greater force. It is, therefore, presumed that the twisting motions between the pelvis and the upper torso during pitching will help create greater length of the trunk muscles that will exert more force.

The non-throwing arm of a skilled pitcher is extended forward prior to the stride phase and is drawn to the trunk while the trunk rotates toward the batter. It can be inferred that this non-throwing arm, when extended forward, will increase the moment of inertia along the longitudinal axis of trunk including the upper torso and upper limb, help suppress the rotation of upper torso during pelvis rotation that precedes, and help increase the twisting movement between upper torso and pelvis of the trunk.

Subsequently, it may be appropriate to conclude that as the arm is drawn to the trunk while the pelvis rotation decelerates, the moment of inertia reduces and the rotational velocity of the upper torso increases. It is expected that an increase in throwing velocities will occur, as rotational velocities of the upper torso increase and then those of the throwing arm connected to the upper torso increase. It can be inferred that the non-throwing arm changes the moment of inertia along the longitudinal axis of trunk including the upper torso and upper limb according to each phase, in order to insure a maximum use of stretch-shortening cycle and force-length relations in the trunk muscles, thus performing a certain function to develop throwing velocities.

No research has been done so far to examine how the non-throwing arm affects throwing velocities. Therefore research on these effects would provide useful information for those who seek a solution to improve pitching mechanics. Studies are required to examine the extent to which throwing velocities will drop and the type of changes that are expected to occur in trunk and throwing arm motions, when the non-throwing arm movement is restricted.

The purpose of our study is to identify the impact on throwing velocities and motions in subjects who deliver a pitch with their non-throwing arms fixed onto the trunk in order to limit motion, and compare with those in normal pitching.

2. Methods

2.1. Subjects

Subjects were 10 male baseball players who belonged to a university baseball team (aged 21.3 ±1.6, height 173.4±7.0cm, weight 71.2±3.4kg, all right-handers). The significance of the research and the test method were explained, and their consent was obtained.

2.2. Test conditions

To help insure easier analysis of motion, subjects were instructed to wear tight fitting pants on the lower-body and to have nothing on the upper-body, or to wear a tight fitting shirt if requested by subjects. All the joints were marked with stretch tape. No baseball glove was worn on the left hand.

Our experiment used official baseballs (weight 0.145kg, circumference 23.0cm) and subjects were instructed to pitch at full speed from the pitching mound (plate height 25cm) toward a home plate 18.44m away and to a catcher. They were given two different conditions: normal pitching and controlled pitching with the non-throwing arm fixed to the trunk (thereafter referred to as normal and restricted condition, respectively) (Figure 1). Subjects were bound with a strong wide rubber band in a way that
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the subjects felt no pain, while their arm motions were restricted (Figure 2).

Sufficient warm-up time was allowed prior to the experiment, and ample pitching exercise was provided prior to each trial until subjects were accustomed to the pitching movements in the test clothing and test settings. The experiment was initiated only after the subjects were certain to pitch at full speed.

Because our methods were to fix the extended non-throwing arm onto the trunk, there was a concern that not only the motions of the non-throwing arm but also the twisting motions of the trunk might be limited. The subjects, however, did not exhibit excessively unnatural motions nor did they claim to do so. Two types of trials were executed in random order, and 5 trials were conducted continuously for each trial condition.

Throwing motions were videotaped (250fps, shutter speed 1/1000sec.) utilizing three electrically synchronized high-speed video cameras (HSV 500C3: nac Image Technology Inc.) and throwing velocities were recorded from behind the catcher with a radar gun (CR-1K: Decatur Electronics Inc) (Figure 1). Prior to filming, 2.30m poles were set up vertically at 9 locations in the 3.00m-deep (pitching direction) and 2.30m-wide pitching area to calibrate the performance area, and then the cameras were adjusted to ensure all of the poles fell into a calibration frame. The three-dimensional coordinate system was defined with the Y-axis as the throwing direction, the Z-axis as the vertical axis and the X-axis to the right of the home plate and perpendicular to the Y-axis and Z-axis.

2.3. Calculation of three-dimensional coordinates

One trial that the highest throwing velocity was recorded by the radar gun for each test condition was used for analysis. Within-subject differences in velocities were 8km/h for normal condition, and 5km/h for restricted condition. Joint centers of both shoulders, both hips, elbow and wrist of the throwing side as well as the baseball were digitized in every video field. Three-dimensional coordinates of these points were calculated by utilizing the Direct Linear Transformation (DLT) method [Abdel-aziz and Karara, (1971)]. Previous studies have found that the stride foot contacts the ground at around 0.10-0.15 sec. prior to the ball release, followed by the large motion of the trunk and throwing arm [Dillman, et al., (1993); Feltner and Dapena, (1986); Fleisig, et al., (1995); Fleisig, et al., (1996); Fleisig, et al., (1999; Miyanishi, et al., (1996); Miyanishi, et al., (1997); Sakurai, et al., (1993)]. Therefore our study analyzed those motions in the time period between 0.3 sec. (75 frames) before and 0.08 sec. (20 frames) after ball release. The moment of ball release was set at zero. A fourth-order digital Butterworth-type filter was used to smooth the three-dimensional coordinates for X, Y and Z respectively with the cutoff frequency of 13.4Hz [Winter, (1990)].

2.4. Calculation of angles

The following is the vector defined for trunk segments to calculate the trunk angles and throwing arm angles. The vector advancing from the left to the right shoulder joint centers was defined as SD, the vector from the left to the right hip joint was defined as HP and the vector from the mid-point of the right and left shoulders to the mid-point of the right and left hip joints was defined as TR. The cross product of two vectors SD and TR was defined as the vector FR (Figure 3).
We used the same method as Stodden, et al., (2001) to evaluate the rotational motions of the trunk, with the upper torso angle defined as an angle between the vector SD projected onto the horizontal plane (XY-plane) and the Y-axis (negative direction), and the hip angle between the vector HP and the Y-axis (Figure 4A). Trunk twist angle was defined as the difference between the pelvis and the upper torso angles (Figure 4A). Next, angles of the shoulder and elbow joint were determined as follows to examine the impact of the trunk motion on the throwing arm. Adduction/abduction angle of the shoulder joint was the angle between the vector projection of the upper arm vector (advancing from the center of the shoulder joint of the throwing arm toward the center of the elbow joint) projected onto the SD-TR plane and the TR [Escamilla, et al., (1998); Fleisig, et al., (1996)]. The horizontal adduction/abduction angle was the angle between the vector projection of the upper arm vector projected onto the SD-FR plane and the SD [Escamilla, et al., (1998); Feltner and Dapena, (1986); Fleisig, et al., (1996); Sakurai, et al., (1990); Sakurai, et al., (1993)]. The internal/external rotation angle was the angle between the vector projection of the forearm vector (advancing from the center of the elbow joint of the throwing arm toward the center of the wrist joint) and the FR in the plane perpendicular to the upper arm vector [Escamilla,
et al., (1998); Fleisig, et al., (1996); Sakurai, et al., (1990); Sakurai, et al., (1993)). The flexion/extension of the elbow joint was the angle made by the upper arm and forearm vectors [Escamilla, et al., (1998); Fleisig, et al., (1996); Sakurai, et al., (1990); Sakurai, et al., (1993); Werner, et al., (1993)]. Angles for the throwing arm are defined in Figure 4B-E.

2.5. Statistical analysis

Comparison was made between the two test conditions for the angles when the trunk reached its maximum twist, when the whole sole of the stride foot contact the mound (SFC), when the shoulder joint reached its maximum external rotation (MER) and when the ball was released (REL), and as to the peak velocities of the upper torso and pelvis rotation, internal rotation of the shoulder joint, extension of the elbow joint and the time those maximal values were reached. A t-test was used to determine a significant difference in means between the two conditions.

The coefficient of correlation was computed using differences in the throwing velocities and variables between the two conditions to identify joint motions that might affect throwing velocities. The criterion for statistical significance was set at $p<0.01$.

3. Results

Table 1 shows mean values and the standard
deviation between the variables for two conditions, and Figure 5, Figure 6, and Figure 7 took a subject T.M. as an example to show time course changes in trunk angles, internal/external rotation angles of the shoulder joint, and angular velocities of internal rotation of the shoulder joint and extension of the elbow joint.

A significant difference ($p<0.001$) was found in velocities for the two test conditions, with $30.9\pm2.9\,m/s$ for restricted condition as opposed to $33.6\pm2.0\,m/s$ for normal condition. One subject exhibited a maximum difference of approximately $20\%$.

Figure 5 shows trunk motions presented in time series. For both conditions, trunk twist angle was largest around $0.16\,sec$. before REL, with upper torso angled at $-10-0$ degrees and pelvis angled at approximately $40\,degrees$. This indicated that the pelvis was oriented more toward the throwing direction. No differences have been found between the two conditions as to the maximum twist angle, the time of occurrence and upper torso/pelvis angles at the time of occurrence. In some subjects peak rotation velocity of the pelvis was attained before their trunks reached maximum twist angle, whereas in others it was attained after. However, the comparison between the two conditions found that the peak rotation velocity of the pelvis was attained significantly earlier in restricted condition ($p<0.01$). There was, however, no difference in the peak rotation velocity of the pelvis. Then the stride foot contacted the mound approximately $0.13\,sec.$ prior to REL, and at this point significant difference was observed in the upper torso angle ($p<0.001$), with $6\pm15\,degrees$ for normal condition as opposed to $17\pm19\,degrees$ for restricted condition. Although there was no significant difference in pelvis angle, twist angle of the trunk exhibited a significant difference, with the values of $43\pm13$ and $34\pm17\,degrees$ respectively ($p<0.01$). Although peak rotation velocity of the upper torso was attained before shoulder joints reached their maximum external rotation, no differences were seen between the two conditions as to the maximum values and time of occurrence. At MER, the upper torso angle was approximately $90\,degrees$, that is, the upper torso rotated more counterclockwise than the pelvis (approximately $75\,degrees$), presenting a negative trunk twist angle. At this point no significant difference was observed in the angles of upper torso, pelvis or trunk twist. No difference was observed in these angles at REL.

Next, discussion shall be made on the throwing arm angles. At SFC, there was a significant difference only in internal/external rotation of the shoulder joint, with larger external rotation observed in restricted condition (Figure 6). The maximum external rotation angle occurred significantly earlier in restricted condition ($p<0.001$), presenting a significantly smaller angle ($p<0.01$) (Figure 6). At REL, there was a significant difference only in flexion/extension.
angle of the elbow joint ($p<0.01$), with restricted condition exhibiting a slightly larger flexion angle. Peak angular velocities of the elbow extension and shoulder internal rotation were significantly lower in restricted condition ($p<0.01$ in both cases), however no significant difference was observed in time of occurrence (Figure 7).

Regarding correlations between differences in throwing velocities and variables for the two conditions, there was a significant positive correlation in the maximum trunk twist angle and the twist angle at SFC, with the correlation coefficient of 0.766 and 0.829 respectively ($p<0.01$ in both cases) (Figure 8). Therefore it can be implied that players who had a larger drop in throwing velocities also experienced larger reduction in twist angle of the trunk.

4. Discussion

Our study has found differences in throwing velocities and motions, however there are possibilities that trials performed in unfamiliar settings caused those differences, as the settings, where the non-throwing arm was fixed to the body using a rubber band, were extremely unusual. However, the subjects were instructed to do pitching practice until they could pitch at full speed. In addition to that, throwing velocity measurements by the radar gun indicated that within-subject differences were maximum 8km/h in normal condition as opposed to maximum 5km/h in restricted condition, and thus it might be reasonable to conclude that the subjects learned how to deliver pitches under the given conditions. Judging from the tendencies developed in all subjects, the findings in our study were more likely to be affected by fixing the throwing arm to trunk rather than by pitching in unfamiliar settings.

It is undeniable that our interpretation has its limitations due to the possibility that our study method not only limited rotational motions of the non-throwing arm but also twisting motion between the upper torso and pelvis. However, the maximum twist angle of the trunk was 44±12 degrees, presenting no significant difference from normal condition, therefore it can be inferred that no major restriction was given to trunk twist. Our findings suggest that differences in trunk twist, which occurred in succeeding phases, were mainly caused by utilization of non-throwing arm. The factors that account for the differences between the two conditions will be discussed below.

In this study, the average velocity for normal condition was 33.6m/s, which is much the same as those previously reported for other college players (35m/s: Escamilla, et al., 1998; 33.5m/s: Feltner and Dapena, 1986; 35m/s: Fleisig, 1999; 29.8m/s: Miyanishi, et al., 1996; 29.8m/s: Miyanishi, et al., 1997; 35.0m/s: Sakurai, et al., 1993) and the status of shoulder and elbow joint angles agrees with the findings in previous studies [Dillman, et
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The difference in twisting angle of the trunk, this did not affect the rotation velocity of the upper torso. The reason that the peak rotation velocity of pelvis was reached earlier in restricted condition might be that rotation angle of the upper torso was large around the stride foot contact phase, causing less twisting in the trunk, and then generating smaller torque to rotate the pelvis to the right.

In conclusion, the difference made in the trunk for the two conditions is that fixing the non-throwing arm will advance rotation in the upper torso at SFC, resulting in less twisting of the upper torso and pelvis. Our study found neither difference in the upper torso angle at REL nor any time difference from SFC through REL, therefore it can be concluded that mechanical work involved in upper torso rotation decreased, resulting in reduced power in the trunk muscles.

Our study has shown that a fixed non-throwing arm will affect trunk rotation as well as motions of the throwing arm. Although extension of the elbow joint and internal rotation of the shoulder joint are variables used to analyze the throwing arm, as these joint motions play a major role in acceleration of ball velocity [Dillman, et al., (1993); Escamilla, et al., (1998); Feltner and Dapena, (1986); Fleisig et al., (1996); Fleisig, et al., (1999); Matsuo, et al., (2001); Miyanishi, et al., (1996); Pappas, et al., (1985); Werner, et al., (1993)], their maximum angular velocities had a significant drop in restricted condition, indicating this can be a major cause of reduced throwing velocity. Notably, it is assumed that reduction in maximum external rotation angle caused reduction in stretch of the internal rotation muscles, resulting in a drop in internal rotation angular velocity. Previous studies have found that a higher throwing velocity group exhibited larger maximum external rotation angle as opposed to a lower throwing velocity group [Matsuo, et al., (2001)]. An analysis conducted on motions of a pitchers in actual baseball games showed that the maximum external rotation angle of the shoulder joint was smaller, and that the throwing velocity dropped in the second-half of the game compared to the first-half [Murray, et al., (2001)]. One study reported that when a subject delivered pitches using an internal rotation motion alone, while his trunk was fixed for this experiment, the wrist velocity developed higher in trials in which he did not stop his motion, while switching from external to internal rotations, compared with allowing 1 or 2 seconds of motionlessness [Elliot, et al., (1999)]. These findings suggest that an effective way of improving throwing velocity is to externally rotate the shoulder joint further, followed by the swift internal rotation motion. It appears that external rotation of the shoulder joint will occur when horizontal adduction torque generates a forward force and abduction torque generates an upward force in the

al., (1993); Escamilla, et al., (1998); Feltner and Dapena, (1986); Fleisig, et al., (1996); Fleisig, et al., (1999); Matsuo, et al., (2001); Sakurai, et al., (1993); Werner, et al., (1993)]. Therefore it is suggested that the subjects participating in our study were typical university-level baseball players and were skilled in pitching mechanics. Our findings have shown that the average velocity drop caused by fixing the throwing arm on the trunk was around 10%, suggesting that the magnitude of the impact on the non-throwing arm was approximately 10%. The first influential factor for the velocity drop would be decreased twisting angle of the trunk.

Our study has shown that fixing the non-throwing arm caused the upper torso to develop a larger angle in the stride foot contact phase and the front upper torso to advance more toward the pitching direction, resulting in less twisting in trunk. This indicates that an unused non-throwing arm will restrict control of the upper torso to result in less twisting in the trunk. Likewise strong correlation between differences in the angle and throwing velocity suggests that the trunk be twisted in this phase. Furthermore, the significant correlation was found between differences in maximum trunk twist angle and throwing velocity suggests the possibility that this maximum trunk twist angle might affect throwing velocity. Stodden, et al., (2001) instructed professional, university and high school-level pitchers to deliver sets of 10 pitches at full speed to create 1.8m/s variation in throwing velocities, and found that increasing the average rotation velocity of the pelvis from stride foot contact through the maximum external rotation phase of shoulder joint, as well as increasing the average rotation velocity of the upper torso from the maximum external rotation of shoulder joint through the ball release phase will help improve throwing velocity. However our study found no difference in maximum rotation velocities of the pelvis and upper torso between the two conditions, nor any correlation between those differences and throwing velocities. Although fixing the non-throwing arm created a difference in twisting angle of the trunk, this did not affect the rotation velocity of the upper torso. The reason that the peak rotation velocity of pelvis was reached earlier in restricted condition might be that rotation angle of the upper torso was large around the stride foot contact phase, causing less twisting in the trunk, and then generating smaller torque to rotate the pelvis to the right.
proximal part of the upper arm [Feltner and Dapena, (1986)]. Therefore, as shown in our study, reduced twist angle of the trunk as well as reduced stretch of the trunk muscles might cause the torque, which is applied to the throwing arm, to be reduced, resulting in decreased external rotation angle.

In restricted condition, the elbow flexion angle at REL was large and its maximum extension angular velocity was small. It is known that extension of the elbow joint is subject to the torque produced by rotation of the body in addition to actions of the main agonist, the triceps brachii [Toyoshima, et al., (1974)], therefore this phenomenon indicates that decreased twist of the trunk will cause a drop in the torque applied to the throwing arm. It is then suggested that the elbow joint, when flexed in greater degrees, will shorten the distance between rotation axis of the trunk and ball, and as moment arm decreases, throwing velocities will drop.

As mentioned above, our study has shown that restricted motions of the non-throwing arm have a large impact on internal/external rotation of the shoulder joint and flexion/extension of the elbow joint, whose relationships with throwing velocities have been reported before. Therefore, their remarkable contribution to the throwing velocities has been reaffirmed.

Our study has shown that a fixed non-throwing arm will cause decreases in the twist of the trunk, maximum external rotation angle of the throwing arm, internal rotation velocity and extension velocity of elbow joint, resulting in a drop in throwing velocity. These findings show possibilities that increasing the twist of the trunk and external rotation angle of the shoulder joint are effective in improving velocity for normal pitching. Further study needs to be done to determine whether improvement of the non-throwing arm movement can change motions of the trunk and throwing arm, and finally affect throwing velocity. In addition, a glove used in an actual ball game will affect the mass and moment of inertia of the entire non-throwing arm, and therefore quantification for all these is required.

References
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