THE ROLE OF HUMERAL ELEVATION OF THE NON-THROWING ARM ON MAXIMUM BALL VELOCITY IN UNCONSTRAINED OVERARM THROW

Allan Fu[1], Richard Smith[1], Steve Cobley[1] and Ross Sanders[1]

Discipline of Exercise and Sports Science, The University of Sydney, Sydney, Australia[1]

The purpose of this study was to identify the role of humeral elevation of the non-throwing arm in relation to maximum ball velocity (MBV) in unconstrained overarm throws in children aged 12-14. 3D motion analysis was used to investigate the throwing technique of 144 students. The group was classified as 'skilled' or 'less skilled' based on MBV at release. Joints kinematics and timing of segmental sequencing (SS) based on maximum angular velocity (MAV) were quantified. Humeral elevation of the non-throwing arm had an important role in maximising ball release velocity. It had moderate to good correlation with MBV and MAV of other joints. 'Skilled' children were characterized by significantly more humeral elevation, MAV, faster humeral angular motions from an elevated position in the non-throwing arm and better SS in the throwing arm than the 'less skilled'.

KEY WORDS: segmental sequencing, movement pattern, kinematics, coaching

INTRODUCTION: There are many investigations of movement patterns focusing on the throwing arm in different sports. However, little attention has been paid to the role of the non-throwing arm. Murata (2001) found that there was less shoulder joint movement on the non-throwing side in skilled than unskilled pitchers and that it was a characteristic of a skilful pitcher to achieve a higher ball velocity. Ishida and Hirano (2004) found that there was a significant decrease in the elbow extension angle at the time of ball release when constraining the non-throwing arm in an abducted position during the maximum throw. He also found that the pelvis achieved maximum angular velocity (MAV) earlier in the restricted throw than the normal throw. This experiment provided insights that non-throwing arm positions affected joint range of motion (ROM) and segmental sequencing (SS) thereby reducing MBV. However, the effect of the non-throwing arm on the normal throwing pattern, and the effect of humeral elevation on maximum ball velocity (MBV) has not been established.

Despite the lack of evidence relating to the benefits of non-throwing arm elevation, elevating the arm has been suggested as useful to maintain balance(Department of Education Western Australia, 2013). It is also not uncommon for coaches to instruct children to point at the target with the non-throwing arm prior to throwing. However, this may disrupt the motor coordination for the throwing sequence. Therefore, it is important to understand the influence of humeral elevation of the non-throwing arm in relation to MBV without the influence of sport-specific constraints.

Thus, the purpose of this study was to determine the contribution of humeral elevation of the non-throwing arm in unconstrained throwing for maximum release speed.

METHODS: Throws with the right hand of 144 right handed grade 8 students (59 girls, 85 boys, age 13.04years ±0.35 (mean±SD), height 1.61m±0.09 and weight 55.70kg±14.27) were captured in a biomechanics laboratory using a 14 camera three-dimensional motion analysis system (Cortex Version 6.0, Santa Rosa, USA) with sampling rate at 100 Hz. The testing area of 12mX8m had no obvious visual target except a net 8m wide hanging vertically 4m from the thrower to arrest the motion of the ball. This allowed the participants to throw the ball as fast and as hard as they could without inhibition.

Participants were marked with a total of 52 markers (diameter, 1.4cm) fixed with double-face adhesive tape on the anatomical sites using the joint coordinate system recommended by the International Society of Biomechanics. A standard baseball was wrapped with reflective tape.

Participants completed a warm up session for five minutes comprising stretching and practices prior to the assessment. Following a warm up and practice throw, participants threw until two valid throws were recorded. The throws were considered valid when the ball was released with the dominant hand above the shoulder towards the mid-regions of the net in accordance with those instructions issued consistently by the tester.

Kinematic variables of interest were calculated from the filtered coordinate data with a cut-off frequency of 6Hz. These included time series motion of the pelvis rotation, torso rotation, trunk tilt and trunk lean, left and right humeral elevations, right shoulder internal/external rotation, right shoulder flexion, elbow extension, wrist flexion, and their respective maxima and minima, ROM and velocity. The choice of these variables was based on the rationale of kinetic link theory (KLT) (Kreighbaum & Barthels, 1996) and previous studies on kinematics and SS of the trunk (Oyama et al., 2014; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001) and the throwing arm (Ferdinands, Kersting, & Marshall, 2013; Kageyama, Sugiyama, Takai, Kanehisa, & Maeda, 2014; Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001). Humeral elevation was calculated as the Cardan angle between the line of the humerus and the line joining the midpoints of the hips and shoulders expressed with the neutral (0 degrees) being the plane perpendicular to that line with positive being above the plane and negative being below the plane. The maximum ball velocities were normalized ($\text{ballVel}_{\text{Norm}}$) for each participant by dividing by their stature. The association among $\text{ballVel}_{\text{Norm}}$, angular ROM and the maximum and minimum angular velocity of selected body segments and joints was quantified using Pearson's r correlation. To compare the movement characteristics of 'skilled' and 'less skilled' children, the whole cohort was divided into four quartiles, each of 36 students, according to $\text{ballVel}_{\text{Norm}}$. The ROM and MAV in the quartile with lowest $\text{ballVel}_{\text{Norm}}$ (i.e. less skilled) were compared with the quartile with highest $\text{ballVel}_{\text{Norm}}$ (i.e. skilled) using independent t-tests. The sequencing of MAV of selected segments and joints in each group were visualized using a line graph and compared using independent t-tests. Differences in left humeral elevation angle ($\text{LHElev}_{\text{Ang}}$) across the time of the throwing action were investigated by plotting 95%CI intervals of the true mean for each group. Significant differences corresponding to specific times were evident by the CI envelopes being disjoint (not overlapping). All tests with a p value of <0.05 were considered statistically significant.

Table 1 Correlation of left humeral elevation with normalized maximum ball velocity, range of motion and maximum and minimum angular velocity of selected joints

		Left Humeral Elevation (non-throwing arm)		
		Range of Motion	Maximum Angular Velocity	Minimum Angular Velocity
Normalized maximum ball velocity		r=0.577, p<0.001	r=0.501, p<0.001	r=-0.653, p<0.001
Range of Motion	Pelvis rotation	r=0.463, p<0.001	r=0.396, p<0.001	r=-0.513, p<0.001
	Torso Rotation	r=0.544, p<0.001	r=0.329, p<0.001	r=-0.499, p<0.001
	Right Shoulder Internal/External Rotation	r=0.538, p<0.001	r=0.433, p<0.001	r=-0.593, p<0.001
	Right Shoulder flexion	r=0.450, p<0.001	r=0.360, p<0.001	r=-0.413, p<0.001
	Right Elbow Extension	r=0.391, p<0.001	**r=0.145, p=0.083**	r=-0.292, p<0.001
	Right Wrist Flexion	**r=-0.020, p=0.811**	**r=-0.089, p=0.291**	**r=0.083, p=0.322**
Maximum Angular Velocity	Pelvis rotation	r=0.594, p<0.001	r=0.577, p<0.001	r=-0.631, p<0.001
	Torso Rotation	r=0.608, p<0.001	r=0.511, p<0.001	r=-0.633, p<0.001
	Right Shoulder Internal/External Rotation	r=0.486, p<0.001	r=0.429, p<0.001	r=-0.479, p<0.001
	Right Shoulder flexion	r=0.560, p<0.001	r=0.500, p<0.001	r=-0.664, p<0.001
	Right Elbow Extension	r=0.578, p<0.001	r=0.374, p<0.001	r=-0.551, p<0.001
	Right Wrist Flexion	r=0.174, p=0.037	r=0.210, p=0.012	r=-0.259, p=0.002

Note 1: All pairs of correlations were significant correlations except the bolded cells.
Note 2: Cells with moderate to good correlation (r>0.5) are shaded in grey.

RESULTS: ROM and MAV of the left humeral elevation had moderate to good correlations with $\text{ballVel}_{\text{Norm}}$ and fair to good correlation with ROM and MAV of other joints (Table 1).

Independent t-tests showed that the ‘skilled’ had significantly higher maximum ROM for all joints than the ‘less skilled’. All MAV of the ‘skilled’ children were significantly higher than the ‘less skilled’ except for left trunk lean. There were significant temporal differences in the MAV of left humeral elevation, pelvis rotation and right shoulder flexion. The ‘skilled’ children followed the KLT SS except for the right wrist flexion, while the ‘less skilled’ had a ‘reverse order’ in the throwing arm (Figure 1). Between groups $LHElev_{Ang}$ across the throwing cycle was very different both in amplitude and shape (Figure 2). The $LHElev_{Ang}$ of the skilled group were significantly higher than the less skilled group in the middle third of the throw cycle and $LHElev_{Ang}$ reached maximum at ~20^0 below the level of the shoulders ~0.3s before the ball release.

DISCUSSION: This was the first study investigating the movement pattern and SS with consideration of the non-throwing arm in unrestricted overarm throws. This is important as it provides information for coaches to understand the characteristics of skilled throwing to identify children in need of additional skills training and to develop throwing for performance in sports. This is particularly relevant for children 12-14yrs of age because they are participating in group games involving throwing and poor skill contributes to a vicious cycle comprising low levels of skill, participation, and high obesity (Fu, Cobley, & Sanders, 2016).

There are several reasons why left humeral elevation is important. First, both its ROM ($LHElev_{ROM}$) and MAV ($LHElev_{MAV}$) were positively correlated with maximal ball release speed and almost all ROM and MAV in other joints. In general, the larger the $LHElev_{ROM}$ and $LHElev_{MAV}$, the better the sports performance (i.e. faster $ballVel_{Norm}$). When $LHElev_{ROM}$ increases, the ROM and MAV of all other joints involved in the SS increase positively. In particular, the good correlation of $LHElev_{MAV}$ with MAV of pelvis and torso rotation indicates its role in initiating the SS which starts from the pelvis and progresses through the torso to the throwing upper limbs in accordance with the KLT.

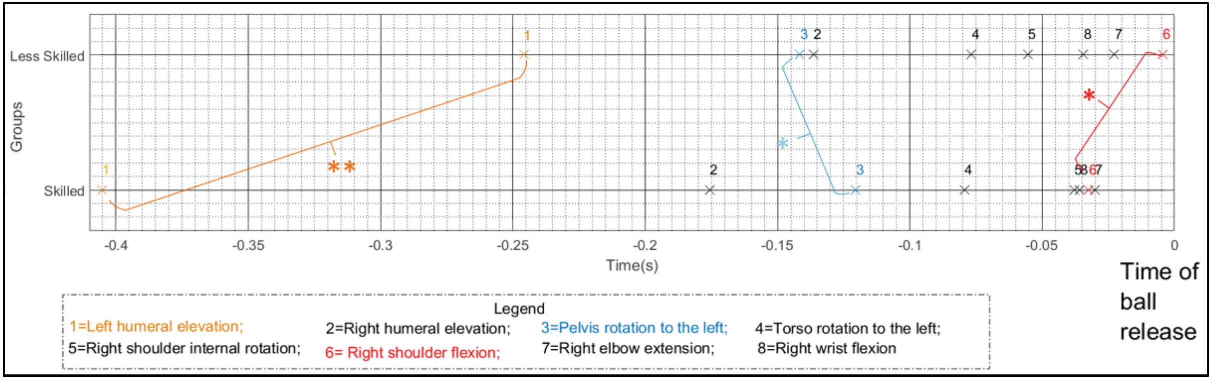

Figure 1 Mean occurrence timings of maximal joint angular velocities of the throwing arm between two groups. The numbers represent the direction of movement of respective joints and segments. Significant differences between two groups: **P=0.001, *P<0.05

Secondly, a larger $LHElev_{Ang}$ is a distinguishing feature of ‘skilled’ children throughout the throwing cycle (Figure 2). They had three times more ROM than the ‘less skilled’ children, and a greater velocity in elevating and depressing the humerus manifest in the steep positive and negative slopes in Figure 2. Based on the correlations and application of biomechanical principles, the downward motion of the left humerus from an elevated position is likely to facilitate pelvis and torso rotation when the mass of the left humerus was drawn towards the body. This reduces the moment of inertia about the longitudinal axis of body. Another contributing factor is likely to be the transfer of momentum from the non-throwing arm to the throwing arm indicated by the negative correlation of the minimum elevation angular velocity with MAV of other joints.

Additionally, ‘skilled’ children had better SS than the ‘less skilled’ children (Figure 1). The ‘skilled’ group basically followed the SS from the pelvis to the throwing arm except the wrist which took place before elbow extension. However, the ‘less skilled’ children had peaked right shoulder flexion at the last which was significantly different from the ‘skilled’ group. This sequence was considered inefficient according to KLT. Conversely, the SS of the skilled children is in general agreement with the findings of studies of sport specific throwing techniques (Ferdinands et al., 2013; Oyama et al., 2014). Furthermore, the effect of lower limb kinematics on the SS of the trunk and throwing arm are not clear and this should be considered in future studies.

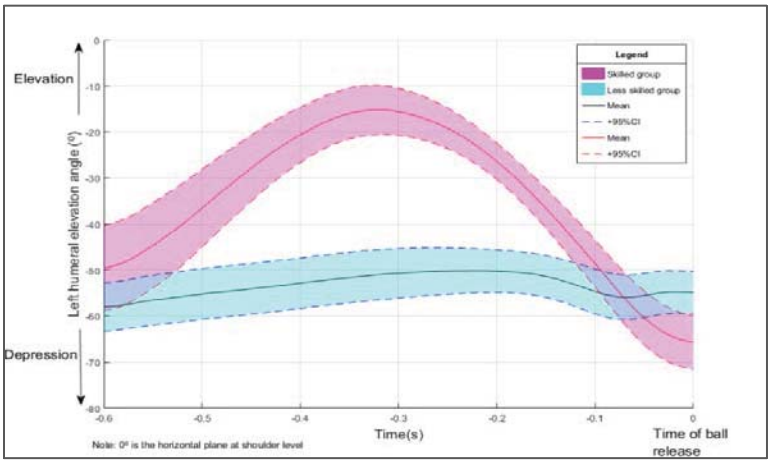

Figure 2 The left humeral angle - time graph for skilled and less skilled group

CONCLUSION: ROM of humeral elevation, MAV of humeral elevation and MAV of humeral depression of the non-throwing arm is associated with MBV in unconstrained overarm throwing. The non-throwing arm of children who had better throwing skill, had larger ROM, MAV and better SS than children who were 'less skilled'. An important implication for practice is that coaches should not recommend to children using the non-throwing arm for balance or targeting for maximum ball release as this not only disturbs movement patterns but also neglects the influence of the non-throwing arm on the throwing arm.

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