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ORIGINAL

Relationship between the Ball Velocity and Upper Extremity Kinematic Variables during an Overarm Throwing Task of Inexperienced Individuals

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Objective: The aim of this study was to investigate the relationship between the ball velocity and the upper extremity kinematics for both dominant and non-dominant side in inexperienced participants about an overarm throwing task.

Method: Seven women who are inexperienced in overarm throwing participated in this study (Age: 25.1 ± 2.4 years, Height: 160.8 ± 3.5; Weight 56.5 ± 7.8). Participants visit the laboratory for three days with one day rest between test sessions. Whole body 3-dimensional (3D) motion capture was recorded during the overarm throwing trials with ten cameras Vicon motion analysis system (T-10, T40, Oxford Metrics Ltd, UK). Total 45 overarm throwing were recorded for each side for each test session. Ball speed also was measured 3 meters away behind the subjects and recorded for every trial.

Results: Mean ball velocity was higher for dominant hand compared to non-dominant hand (p <.05). Trunk segment variables (maximum angles and angular velocities) showed the most consistent relationship with the ball velocity.

Conclusion: The importance of the trunk segment during the throwing activities can be seen in some individuals. But inconsistent results between subjects emphasize the importance of the individuals' movement patterns especially for bilateral sports. The future studies should be conduct about the sequence of segments, kinetic variables and effect of training.

Keywords: Overarm throwing, Ball velocity, Upper extremity, Inexperienced, Kinematics

INTRODUCTION

Overarm throwing like movements is frequently used in several sports such as baseball, softball, volleyball, tennis and many other sports. It is a highly complicated movement which needs the coordination of several segments for optimal performance. There are extensive overarm throwing studies in the literature, especially for baseball pitching (Chu, Fleisig, Simpson, & Andrews, 2009; Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998; Werner, Suri, Guido, Meister, & Jones, 2008; Wilk, Meister, Fleisig, & Andrews, 2000). It was reported there were differences in ball velocity and kinematic variables according to the players' levels and pitching type during baseball pitching (Escamilla et al., 1998; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Lee, 2007; Woo & Jung, 2009). It was emphasized that higher maximum angular velocities of the trunk and upper extremities are important for faster ball velocities rather than the maximum angles (Fleisig et al., 1999; Seroyer et al., 2010; Werner et al., 2008).

These previous studies show that there is a relationship between the ball velocity and kinematic variables. However, these studies are mostly consisting of athletes who are training regularly. It is unknown that how these kinematic variables related with ball velocities at the early stage of skill learning. Furthermore, several studies investigated the differences between the dominant and non-dominant side during the throwing motions. It was reported that the non-dominant sides have slower ball speeds, decreased shoulder external rotation, elbow flexion, shoulder internal rotation and increased lateral flexion and shoulder abduction (Sachlikidis & Salter, 2007; van den Tillaar & Ettema, 2009). However, these studies only compared the differences between the dominant and non-dominant side. Therefore, there is a need for investigating the relationship between the ball velocity and kinematic variables according to the dominant and non-dominant side at the early stage of skill learning.

It is important to understand whether that human body has enough information from their kinesthetic senses for throwing faster balls at the beginning of skill learning in complicated movements such as overarm throwing. Extensive previous studies about overarm throwing can be used to evaluate the movements of the novices for better performance and may give insights to the coaches which parameters should be focused at the early stages of skill learning. It has been hypothesized that participants will show higher ball velocities and better involvement of upper extremities for the dominant side because of their general use of the dominant hand in daily life. Also, the differed relationship between the ball velocity and kinematic parameters for each side may give important insights for better skill learning processes in future.

Therefore, the aim of this study was to investigate the relationship between the ball velocity and the upper extremity kinematics for both dominant and non-dominant side in inexperienced participants while performing an overarm throwing task.

METHODS

1. Participants

Healthy seven women at their 20s and 30s who are inexperienced in overarm throwing participated in this study (Age: 25.1 ± 2.4 years, Height: 160.8 ± 3.5; Weight 56.5 ± 7.8). Participants informed that they need to refrain any training or feedback about overarm throwing throughout this research. All participants were right handed. Participants excluded if they have any upper extremity surgery in the last 2 years or have an upper injury in the last 6 months. Prior to the study, all subjects gave informed written consent, and the study was approved by the Institutional Review Board.

2. Procedure

Participants visit the laboratory for three days with one day rest between test sessions. Whole body 3-dimensional (3D) motion capture was recorded during the overarm throwing trials with ten cameras Vicon motion analysis system (T-10, T40, Oxford Metrics Ltd, UK). The Kinematic data were recorded at 200 Hz sampling rate. Markers and cluster markers were placed to anatomical landmarks and extremities for creating a 14 segment model consisted of hands, forearms, upper arms, trunk, pelvis, thighs, shanks, and feet were created for each participant (Gates, Walters, Cowley, Wilken, & Resnik, 2016). However, lower extremity results were not used for data analysis. A reflective tape was also affixed on the ball to define the ball release.

They performed 15 overarm throwing for each dominant and non-dominant side in every test session (total of 3 sessions). Participants were asked to throw the ball "as fast as possible" to the foam cushion (app. 3 m x 3 m) approximately 4 m away from the participant. Participants performed overarm throws at their comfortable standing position. Total 45 overarm throwing were recorded for each side. Ball speed also was measured 3 meters away behind the subjects with a speed gun and recorded for every trial. Averagely 33 ± 4.7 trials for dominant and 32.8 ± 5.2 trial were included for statistical analysis for each subject in this study.

3. Data analysis

Kinematic data were processed first for marker labeling at Vicon Nexus Software (version 1.8.5, Oxford Metrics Ltd, UK). Visual3d (version 5, C-Motion, USA) were used to calculate the kinematic values. A previously described model was used to calculate kinematic variables (Gates et al., 2016).

Two events were selected as start of the movement (distance of the hand moves farther from the trunk %10 from the initial point and ball release. Calculated angles were filtered by a low-pass fourth order Butterworth filter with a 13.4 Hz as suggested before by other researchers for baseball pitching (Chu et al., 2009; Escamillia et al., 2007; Fleisig et al., 1999). First three trials for each condition and trials with missing markers or gimbal lock occurrence were discarded.

International Society of Biomechanics (ISB) recommendations were used to define all upper body segments' joint centers and local coordinate systems (Wu et al., 2005) except the wrist local coordinate system (Rao, Bontrager, Gronley, Newsam, & Perry, 1996).

Shoulder angles were described in order as the plane of elevation (Y'), elevation (X) and axial rotation (Y''). Elbow angles were described as flexion - extension (Z), carrying angle (X) and pronation-supination (Y). Wrist angles were described as flexion - extension (Z) ulnar - radial deviation (X), pronation - supination (Y). Thorax angle relative to the globe coordinate system were described as lateral flexion, axial rotation, and flexion - extension.

Joint angular velocities defined according to the parent segment for each joint. Parent segments defined as trunk for upper arm, upper arm for elbow, wrist for forearm. Maximum values for each variable used for statistical analysis.

Maximum angles of trunk lateral flexion of the throwing side, trunk external rotation, trunk extension, humeral elevation, the humeral plane of elevation posteriorly, humeral external rotation, elbow flexion and wrist extension were reported for each throwing side.

Maximum angular velocities of trunk lateral flexion to the contralateral side, trunk internal rotation, trunk flexion, humeral elevation, humeral plane of elevation anteriorly, humeral internal rotation, elbow extension, and wrist extension were reported for each throwing side.

A paired sample t-tests were used to investigate the difference between the dominant and non-dominant side ball speed. A Shapiro-Wilk test used to investigate the normal distribution of the data set. A Spearman's rank order correlation test used to investigate the relationship between the kinematic variables and ball velocity for each subject because of the violation of normal distribution assumption. The significance level was set as .05.

RESULTS

Paired samples t-test results of mean ball velocity for the dominant and non-dominant hand of the whole subjects were shown in Table 1. There was a significant difference between the dominant and non-

Table 1. Mean Ball velocity and paired samples *t*-test results

Subjects	Side	Ball Velocity (Mean ± SD)	*t*	df	*p*
1	D	47.8 ± 6.5	7.888	30	<.001
	ND	37.1 ± 3.7			
2	D	41.1 ± 2.9	3.087	27	<.01
	ND	37.9 ± 3.8			
3	D	44.7 ± 2.4	14.457	34	<.001
	ND	36.1 ± 2.7			
4	D	47.5 ± 4.6	4.696	35	<.001
	ND	42.7 ± 3.4			
5	D	42.3 ± 2.3	2.710	34	<.01
	ND	40.9 ± 3.08			
6	D	44.3 ± 1.9	19.581	34	<.001
	ND	37.1 ± 1.8			
7	D	47.8 ± 3.8	9.380	22	<.001
	ND	39.5 ± 2.8			

D: Dominant; ND: Non-Dominant

dominant side ball velocity for all subjects.

The relationship between maximum angles, angular velocities and the ball velocity for dominant and non-dominant side showed for each participant at Table 2 and Table 3, respectively.

One of the most consistent variables was trunk lateral flexion maximum angle which is showed a moderate positive relationship with ball velocity for the non-dominant side in three participants. Also, two participants showed a positive moderate relationship between the ball velocity and trunk extension and rotation maximum angle. However, other variables showed positive and negative relationships with ball velocity between subjects. Most subjects showed a statistically significant relationship for more than one variable. Only the Subject 6 showed a positive strong relationship for one variable (maximum shoulder external rotation angle). Another positive strong relationship was seen for Subject 1 between the ball velocity and maximum trunk lateral flexion angle. Also, the results showed inconsistent results between sides (i.e. positive relationship for dominant and negative relationship for non-dominant side). Only the Subject 3 showed a positive moderate relationship between the ball velocity and trunk lateral flexion while Subject 7 showed a negative moderate and strong relationship with wrist extension. Only the Subject 4 did not show any relationship between the ball velocity and maximum angles.

Table 2. Spearman's Rank Order Correlation coefficients of ball velocity vs. maximum angles

Side		Subjects 1	2	3	4	5	6	7
Trunk lateral flexion[a]	D		-.339*	.568**				.652**
	ND	.421*		.469*		.551**		
Trunk rotation[b]	D	-.399*						
	ND			.485*		.391*		
Trunk extension	D	.472*						
	ND			.416*		.429*		
Humeral plane of elevation[c]	D		-.390*					.495*
	ND							
Humeral elevation[d]	D			-.416*		.450*		
	ND	-.331*		.434*		-.503*		
Shoulder external rotation	D						.765**	
	ND			.347*				
Elbow flexion	D							
	ND	.396*		-.440*				
Wrist extension	D	-.472*				.476*		-.633**
	ND							-.432*

D: Dominant; ND: Non-Dominant; a: lateral flexion to throwing side; b: External rotation to throwing side; c: Humeral plane of elevation to posteriorly; d: Humeral elevation to posteriorly (extension).
*: $p < .05$, **: $p < .01$

Table 3. Spearman's Rank Order Correlation coefficients of ball velocity vs. maximum angular velocities

Side		Subjects						
		1	2	3	4	5	6	7
Trunk lateral flexion[a]	D			.417*				.549*
	ND	.401*						
Trunk rotation[b]	D		.344*	.435*				
	ND			.466*		.347*		
Trunk flexion	D	.411*	.342*					.739**
	ND	.522**		.484*				
Humeral plane of elevation[c]	D			.406*	.403*			
	ND							
Humeral elevation[d]	D				.496*			
	ND					-.378*		
Shoulder internal rotation	D					.431*		
	ND	-.411*				-.374*		
Elbow extension	D			-.447*				
	ND							.475*
Wrist flexion	D					.406*	-.387*	
	ND							

D: Dominant; ND: Non-Dominant; a: Lateral flexion to contralateral side; b: Internal rotation to contralateral side; c: Humeral plane of elevation to anteriorly; d: Humeral elevation to anteriorly (flexion).
*: $p < .05$, **: $p < .01$

Most consistent variable for the maximum angular velocities was trunk flexion which is showed weak to strong relationship in three and two participants for dominant side and non-dominant side, respectively. Also, trunk maximum angular velocities for three rotations and humeral plane of elevation showed only positive relationships in maximum two participants. Only the Subject 1 and 3 showed consistent positive moderate relationship between the sides for maximum trunk flexion and trunk lateral flexion angular velocity, respectively.

DISCUSSION

In our study, the relationship between the ball velocity and the kinematic parameters was investigated to explain which movements should be focused on the early acquisition of skill learning for overarm throwing.

The results showed mostly inconsistent relationships between the throwing sides and subjects. These results can be caused by different movement strategies used by the participants and each side. Most consistent segment according to results was trunk which is the biggest segment Involved the throwing movement.

A previous study showed that there were differences according to the players' level for ball velocity, elbow flexion angle, upper trunk velocity, elbow extension velocity and maximum internal rotation velocity (Fleisig et al., 1999). Werner et al. (2008) reported that maximum shoulder external rotation angle, shoulder angular velocity, and elbow extension angular velocity have a positive relationship with ball velocity in collegiate baseball players. It is evident that angular velocities more important than the than the maximum angles because of the indifferences according to the players' levels (Fleisig et al., 1999; Werner et al., 2008). However, our results showed no evident patterns for every participant. It is expected because of the lack of experience of our participants. Also, lack of any other feedback can lead each participant to prefer different movement strategies (such as relying on only the trunk or shoulder or elbow) to throw faster balls like the different level players.

Trunk angular velocities are especially important in throwing activities because of its high contribution to torque production (Lin et al., 2003; Oyama et al., 2014; Seroyer et al., 2010). Our results can be supported partly by previous researchers because of the consistent positive relationship between some of the participants even though the majority of the group showed no relationship with trunk angular velocities. But this relationship was mostly on one side (dominant or non-dominant). It can be interpreted as the some of the participants were able to use their trunk segments more effectively for dominant sides while the others rely the trunk on the non-dominant side.

Upper extremities for the non-dominant side showed an inconsistent and mostly negative relationship with ball velocity which is opposite with the literature. It can be caused by the improper trunk movement sequence relative to upper extremities which failed to produce needed torques for faster ball velocity. As cited in Seroyer et al. (2010), Kibler and Chandler reported that %34 higher shoulder rotation velocity is needed if there is a %20 decrease in kinetic energy transfer from trunk and hip. Therefore, the transfer of the produced torque from trunk to the upper extremities probably impaired for the non-dominant side. Furthermore, even the increased upper extremity velocities were not enough to produce faster throws to compensate it.

The literature used to compare of this study's results can be used as a guide for novices even though these studies conducted on experienced players. Results of this study showed that individualistic approach is needed at the early skill acquisition. Coaches should not presume that each person needs to learn in the same way for an effective skill acquisition. Because some of them may already know how to use their segments effectively than the others. Also, lack of consistency between the sides showed that most of the participants were not able to transfer the positive parts of the movement to the other side during throwing. The usage of the both sides should be encouraged at the early skill acquisition especially for the bilateral sports.

There are some limitations of this study such as small sample size. Lack of consistency makes it hard to generalize the results of this study for bigger populations. Another factor was the level of the throwing skills of the participants even though they have never performed regularly throwing movements. It is hard to say that they did not perform any throwing activities throughout in their life. Also, only the maximum values were analyzed for this study and it is limited to explain all aspects of the skill learning.

CONCLUSION

Coaches should adopt a more individualized style of teaching at the early skill acquisition phase. Also, bilaterality should be another subject to focus on more efficient skill learning. In the future, studies which investigate the relationship between the sequence of segments, kinetic variables, and effect of training should be performed for a better understanding of the early skill acquisition for complicated movements.

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