RELATIONSHIP BETWEEN THE KINEMATICS OF THE TRUNK AND LOWER EXTREMITIES AND BALL VELOCITY DURING THE OVERHAND THROW IN MALE CANOE POLO PLAYERS

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The purpose of this study was to examine the relationship between the motion of the trunk and lower extremities and ball velocity during the overhand throw in canoe polo. Fifteen male national canoe polo team players participated in this study. The overhand throwing motion was captured using a three dimensional motion analysis system. Kinematic and temporal parameters in the trunk and lower extremities were measured and analyzed. Results indicated that five variables were associated with variations in ball velocity. Specifically, as ball velocity increased, canoe polo players showed an increased maximal angular velocity in trunk-tilt sideways, upper torso rotation, and right knee flexion. In addition, the right knee flexion range of motion and time to maximum right knee flexion angular velocity increased as ball velocity increased.

KEY WORDS: kayak, shot, kinetic chain, biomechanics.

INTRODUCTION: Canoe polo is a competitive ball game between two teams of five players. Players paddle polo kayaks, on a well-defined area of water (35 m × 25 m), attempting to score goals against the opposition. The team that scores the most goals wins the game. Chang and Hsieh (2003) found that 80.2% of all throwing during a competitive canoe polo game are overhand throws. The faster the ball is thrown at the goal, the less time defenders and the goalkeeper have to block the shot (Wit & Eliasz, 1998). To generate maximum momentum, the motions of the extremities must form a kinetic chain. In short, coordinated body and limb motions produce the maximum momentum in terminal extremities in the following sequence of motion: stride, pelvis rotation, upper torso rotation, elbow extension, shoulder internal rotation and wrist flexion (Fieisig, Barrentine, Escamilla, & Andrews, 1996). According to previous studies, baseball pitchers with fast pitching velocity exhibit a large forward trunk tilt angle and lead knee extension angular velocity at the instant of ball release (Matsuo, Escamilla, Fleisig, Barrentin, & Andrews, 2001). An increase in their pelvis and upper torso rotation angular velocity results in increasing ball velocity (Stodden, Fleisig, Mclean, Lyman, & Andrews, 2001). However, canoe polo players who sit in a kayak cannot move their trunk and lower extremities as freely; whether this limitation influences the players' overhand throwing motion and ball velocity remains unclear. Thus, the purpose of this study was to examine the relationship between the motion of the trunk and lower extremities and ball velocity during the overhand throw in canoe polo.

METHODS: Fifteen healthy right-handed male national canoe polo team players (mean ± s: age of 28.0 ± 5.9 years, body mass of 76.0 ± 7.7 kg, height of 1.74 ± 0.07 m, and playing experience 12.3 ± 4.5 years) participated in this study. After completing a self-selected warm up, reflective markers were attached to 14 bony landmarks of each participant. To measure ball velocity, the balls were marked with two separate markers. The participants performed an overhand throw from a special canoe polo seat platform. Specifically, the participants were instructed to throw the ball as fast as possible and hit a target (0.7 × 0.7 m, 1.7 m height) that was set at a distance of 4.5 m. This task was performed until five hits were recorded, and then the greatest ball velocity for each participant was analyzed. Overhand throwing motions were captured using an eight digital camera (200 Hz) motion capture system, and examined using Vicon Nexus. The three critical events of the overhand throwing motions were the moment when the participants' right shoulders moved forward (when the right shoulder changed direction from backward to forward), the instant of maximum shoulder external rotation, and the instant of ball release (at the moment the ball leaves the hand, the distance between the wrist marker and the ball marker increases abruptly and dramatically) (Van den Tillaar & Ettema, 2007). Six kinematic parameters were calculated for various instances, using methods previously described (Escamilla, Fleisig, Barrentine, Zheng, & Andrews, 1998; Stodden et al., 2001), and six temporal parameters variables were also calculated. These temporal parameters were shown as relative values, where 0% corresponded to the instant that the participants' right shoulders moved forward and 100% corresponded to the instant of ball release. Means and standard deviations were calculated for all parameters. Finally, Pearson product-moment correlation coefficients were calculated to identify the relationships between the kinematics of the trunk and lower extremities and ball velocity. The significance level was set at $p < .05$.

RESULTS: The mean ball velocity was 14.34 ± 1.45 m/s, with a range of 12.24 to 16.33 m/s. Table 1 shows the trunk and lower extremity kinematics and range of motion parameters during the throw, as well as their correlation with ball velocity. During the throws (i.e., from right shoulder forward to ball release), the participants' trunks continuously moved forward and laterally (i.e., away from the throwing-arm side), their upper torsos and pelvis continuously rotated toward the throwing target region, their two legs moved in opposite directions, the left knee continuously extended, and the right knee continuously flexed. No significant correlations were found among the three critical events between kinematic parameters and ball velocity. Indeed, only the right knee flexion range of motion was significantly correlated with ball velocity. Maximal angular velocity occurred after the following sequence of motion: trunk-tilt forward, trunk-tilt sideways, upper torso rotation, right knee flexion, pelvis rotation, and left knee external extension (Table 2). Within the maximal angular velocity parameters, we found that maximum trunk-tilt sideways angular velocity, maximum upper torso rotation angular velocity, and maximum right knee flexion angular velocity were significantly correlated with ball velocity (Table 2). Among the temporal parameters, the only a significant correlation was found between the time to maximum right knee flexion angular velocity and ball velocity (Table 3).

Table 1
Kinematic parameters during the throw and their correlation with ball velocity (N = 15)

Parameter	Mean	SD	r
Ball velocity (m/s)	14.34	1.45	
Instant of right shoulder forward			
Trunk tilt forward angle (°)	-17.74	2.28	-0.032
Trunk tilt sideways angle (°)	1.04	2.09	0.029
Upper torso orientation (°)	20.59	9.35	0.166
Pelvis orientation (°)	82.03	2.85	0.166
Right knee flexion angle (°)	38.74	6.19	0.131
Left knee flexion angle (°)	55.91	5.35	0.294
Instant of maximum shoulder external rotation			
Trunk tilt forward angle (°)	-8.12	4.02	0.497
Trunk tilt sideways angle (°)	8.63	3.12	0.286
Upper torso orientation (°)	78.92	9.5	0.198
Pelvis orientation (°)	90.16	3.40	0.303
Right knee flexion angle (°)	46.29	5.63	0.223
Left knee flexion angle (°)	45.94	6.85	0.376
Instant of ball release			
Trunk tilt forward angle (°)	-7.12	4.07	0.340
Trunk tilt sideways angle (°)	10.35	2.94	0.410
Upper torso orientation (°)	102.66	8.66	0.247

* Significant correlation (p<.05)

Table 1 (*continued*)

Parameter	Mean	SD	r
Instant of ball release			
Pelvis orientation (°)	94.47	4.18	0.361
Right knee flexion angle (°)	50.39	6.18	0.378
Left knee flexion angle (°)	42.39	8.18	0.300
Range of motion (ROM)			
Trunk-tilt forward ROM (°)	10.17	4.05	0.289
Trunk-tilt sideways ROM (°)	8.97	2.70	0.345
Upper torso rotation ROM (°)	83.39	14.34	0.098
Pelvis rotation ROM (°)	12.45	5.41	0.192
Right knee flexion ROM (°)	11.45	5.34	0.563*
Left knee external ROM (°)	13.99	6.81	0.171

* Significant correlation (p<.05).

Table 2
Maximal angular velocity during the throw and the correlation with ball velocity (N = 15)

Parameter	Mean	SD	r
Maximum trunk-tilt forward angular velocity (°/s)	72.31	26.80	0.416
Maximum trunk-tilt sideways angular velocity (°/s)	65.76	20.33	0.592*
Maximum upper torso rotation angular velocity (°/s)	580.63	94.35	0.577*
Maximum pelvis rotation angular velocity (°/s)	129.88	70.37	0.429
Maximum right knee flexion angular velocity (°/s)	104.78	45.82	0.603*
Maximum left knee external angular velocity (°/s)	142.45	91.60	0.287

* Significant correlation (p<.05).

Table 3
Temporal parameter data and the correlation with maximal ball velocity (N = 15)

Parameter	Mean	SD	r
Instant of right shoulder forward (% throw)	0.00		
Maximum trunk-tilt forward angular velocity (% throw)	64.01	16.39	-0.313
Maximum trunk-tilt sideways angular velocity (% throw)	67.95	11.07	-0.019
Maximum upper torso rotation angular velocity (% throw)	82.51	10.61	-0.179
Maximum right knee flexion angular velocity (% throw)	83.78	12.68	0.537*
Maximum pelvis rotation angular velocity (% throw)	83.99	6.53	0.398
Instant of maximum shoulder external rotation (% throw)	84.28	6.65	-
Maximum left knee external angular velocity (% throw)	85.81	24.14	0.249
Instant of ball release (% throw)	100.00		

* Significant correlation (p<.05).

DISCUSSION: During overhand throws, the trunk and lower extremities initiate a kinetic chain, play a supporting role, and generate momentum. However, because canoe polo players sit in a kayak and place their feet on footrests, their pelvis and lower extremities cannot move freely. This study found that the participants' pelvis rotation movement range and maximum pelvis rotation angular velocity are significantly smaller than baseball pitchers (i.e., the pitchers showed a range of motion and maximum rotation angular velocity of 62° and 637°/s, respectively) (Stodden et al., 2001; Matsuo et al., 2001). Unlike baseball pitchers, canoe polo players cannot benefit from a striding motion and pelvis rotation during throws, which thereby reduces the kinetic-chain effect. Nevertheless, players with increased pelvis and upper torso rotation velocity can transfer the momentum from their torso to their throwing arm and the ball, which leads to increased overall ball velocity (Stodden, Fleisig, Mclean, & Andrews, 2005). This study found that when the maximum trunk-tilt sideways angular velocity and the maximum upper torso rotation angular velocity of the participants increased, their ball velocity also increased. Similar findings for baseball pitchers have been obtained, indicating that baseball pitchers with fast pitching velocity exhibited a high upper torso rotation velocity (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Matsuo et al., 2001; Stodden et al., 2001).

During the throwing, the participants moved their legs in opposite directions, extended their left knee, and flexed their right knee; for their two legs, the ranges of motion and time points at the moment of maximum angular velocity were similar. Moreover, the participants' left knee extension movements resembled the extension movements of baseball pitchers' leading legs: specifically, the leading legs of baseball pitchers have energy-conversion and supporting functions, and the knee extension movement has supporting and stabilizing functions (Matsuo et al, 2001), helps the trunk and throwing arm move forward quickly, and assists in generate momentum to the upper torso and then the throwing arm (Whiting, Gregor, & Halushka, 1991). In the present study, we determined that three parameters related to the right knee were significantly correlated with ball velocity. By increasing right knee movement range and maximum knee flexion angular velocity, and by delaying the occurrence of maximum angular velocity, the participants' ball velocity could be improved. During the throwing, right knee flexion movement helped the right side of the participants' trunks rotate toward the throwing target. This study found that the right knee range of motion and maximum right knee flexion angular velocity increased, the maximum upper torso rotation angular velocity and maximum pelvis rotation angular velocity also significantly increased ($p < .05$). In short, right knee flexion and left knee extension movements during the throwing can facilitate truck rotation and help generate momentum to the trunk and finally to the throwing arm to increase ball velocity.

CONCLUSION: This study identified canoe polo players perform overhand throwing motions, they engage in lateral trunk-tilt, upper torso rotation, and right knee flexion to increase ball velocity.

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