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THE TEMPORAL SEQUENCE OF JOINT KINEMATICS IN A SIDEARM THROW OF A FLYING DISC FOR DISTANCE

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The aim of the present study was to quantify the temporal sequence of joint kinematics in a sidearm throw of a flying disc by skilled throwers. Seven skilled throwers used a sidearm motion to throw a flying disc as far as possible. Three-dimensional kinematics of the trunk, throwing-arm and disc were recorded using a motion capture system, and maximum linear and angular velocity of each joint and the disc were computed. The maximal linear velocity of the elbow occurred before than the maximal linear velocity of the shoulder. This sequence could be due to the timing of maximal shoulder adduction velocity, which occurred earlier than the maximal angular velocities of trunk. In conclusion, coaches and players should consider this temporal order when they technically coach the sidearm motion for disc throws.

KEY WORDS: biomechanics, kinematic chain, coaching

INTRODUCTION: It has been reported that the velocity of the most distal segment of the upper extremity is maximised by the sequential motion of the upper limb that starts with the trunk and ends with the most distal segment such as the hand, ball or racket (Atwater 1979; Elliot et al. 1989; Feltner and Dapena 1989; Liu et al. 2010; Marshall and Elliott 2000). This temporal order of movement is referred to as proximal-to-distal, and is important when attempting to maximise the velocity of the most distal segment of the throwing arm.
Of the activities using a flying disc (hereafter referred to as a disc), Ultimate is the most populated disc sport (World Flying Disc Federation 2012). In the game of Ultimate, the sidearm throw is regarded as a basic and effective throwing skill, and achieving long distances with a sidearm throw is a particularly important skill. Long passes from the sidearm throw are often used as an efficient means of scoring points, and the skill of throwing long distances, in addition to throwing accurately and quickly, is a major focus of practice and training. However, not only novice players but also many experienced players lack good sidearm throwing skills. Knowledge of the optimal throwing mechanics for a sidearm throw is necessary to enable Ultimate players to develop their skills. However, no study was focused on the temporal sequence of joint kinematics. In the sidearm throwing motion, optimal timing of the angular motion of all throwing arm segments could be important to maximise the throwing distance. Therefore, the aim of the present study was to quantify the temporal sequence of joint kinematics during a sidearm disc throw performed by skilled disc throwers. To do this, we focused on the timing of maximum linear and angular velocities of each joint of the throwing arm.

METHODS: Seven male participants were members of a varsity Ultimate team that had won fifth place in the nation championships, and were skilled disc throwers with 3–4 years experience. Participants provided informed consent before the experiment. The participants were instructed to throw an Ultimate regulation disc with maximum effort. The experiments were performed in a gymnasium 72-m long and 32-m wide to eliminate the effects of wind. A motion capture system (Vicon MX, Oxford Metrics Inc., Oxford, UK) was used to collect three-dimensional position data from the reflective markers (600 Hz). The marker-position data were used to calculate the linear velocity of each joint relative to global coordinate system in three-dimensional space, and the joint angles (Wu et al. 2005) and joint angular velocities (Sprigings et al. 1994) of the throwing arm and of the trunk. The throwing movement was analysed from the point of maximum shoulder abduction (MABD) to the point of disc

release (DRL). In addition, the points of maximum shoulder adduction velocity (MV-ADD) and maximum external shoulder rotation (MER) were identified. The joint angle was quantified at each of these four time points (MABD, MV-ADD, MER and DRL; Table 1). The maximum linear and angular velocity between MABD and DRL was identified for each joint.
Statistical analysis was conducted using SPSS v.1.8.0 (SPSS Inc., Chicago. IL). To identify differences in the timing and angular variables, we calculated a one-way ANOVA for all joints. For one-way ANOVA, we used the Tukey and Games-Howell post-hoc tests. Statistical significance was set at $p < 0.05$.

RESULTS: The temporal sequence of maximal linear velocity was elbow, shoulder, wrist, third metacarpal, and then disc (Figure 1). Maximal linear velocity of the elbow occurred significantly earlier than maximal linear velocity of the shoulder ($p < 0.05$), and shoulder occurred significantly earlier than wrist, and third metacarpal occurred significantly earlier than disc.

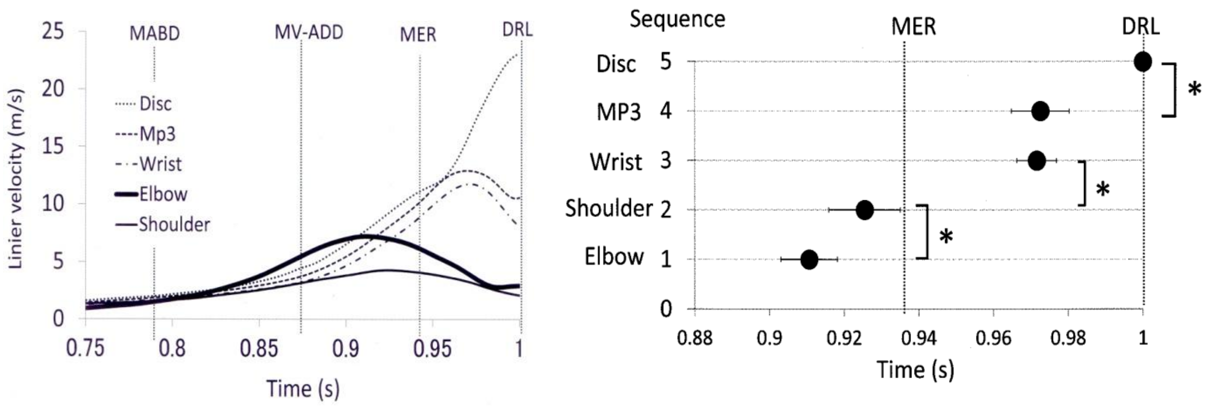

Figure 1: The changes in the mean values of the liner velocity (left) and the time of maximal linear velocity (right) of the shoulder, elbow, wrist, third metacarpal (Mp3) and disc. Error bars represents standard deviation of the time of maximal angular velocity of each joint of all participants. *Significant difference (p < 0.05) between each joint. MER is maximum external rotation of the shoulder. DRL is disc release.

At the instant of MV-ADD, the angles of the trunk relative to R_G were 37.1° ± 10.5°, -23.3° ± 22.5°, and -55.5° ± 17.3° for lateral tilt, anterior tilt, and CCW/CW rotation, respectively. This indicates that the trunk was tilted forward and to the right, and rotated CW. At the instant of DRL these angles were 40.4° ± 9.0°, 3.8° ± 17.3°, and 0.3° ± 16.3° for lateral tilt, anterior tilt, and CW rotation, respectively. This indicates that the trunk was not almost rotated CW. The shoulder abduction angles at the instant of MABD, MV-ADD, MER and DRL were 87.6° ± 15.0°, 65.8° ± 12.8°, 59.0° ± 15.7° and 62.3° ± 16.5°, respectively. From the point of MER to DRL, the angle of shoulder adduction and abduction changed very little (Table 1).

Table 1
Joint angles at selected instants of the sidearm throw (mean ± SD).

Variable (n = 7)	MABD (a)	MV-ADD (b)	MER (c)	DRL (d)	significant difference
Trunk (+/–) (degrees)					
Lateral tilt	34.1±10.2	37.1±10.5	42.0±8.9	40.4±9.0	n. s.
Posterior/Anterior tilt	-34.8±24.5	-23.3±22.5	1.3±13.3	3.8±17.3	a>c, a>d
CCW/CW rotation	-61.5±19.8	-55.6±17.3	-21.1±23.5	0.3±16.3	a>c, a>d, b>c, b>d
Shoulder (+/–)					
Horizontal adduction	19.7±25.1	5.1±16.8	29.5±21.1	36.3±23.4	n. s.
Adduction/Abduction	87.6±15.0	65.8±12.8	59.0±15.7	62.3±16.5	a>c, a>d
External rotation	-61.6±9.0	-78.1±7.3	-144.6±20.9	-88.0±33.0	c>a, c>b, c>d
Elbow					
Flexion	-89.1±10.4	-95.2±10.0	-91.9±13.6	-49.6±7.1	a>d, b>d, c>d
Radio-ulnar					
Supination	-35.7±17.6	-32.6±15.6	-24.9±12.2	-27.0±20.2	n. s.
Wrist (+/–)					
Dorsi flexion	-33.4±11.2	-44.2±5.2	-61.0±9.0	-41.2±12.8	c>a, c>b, c>d
Ulnar/Radial deviation	1.1±5.2	0.4±2.7	-1.8±2.2	1.8±3.5	n. s.
Time (s)	0.786±0.048	0.875±0.014	0.938±0.016	1.000	

Note: MABD = maximum abduction of the shoulder; MV-ADD = maximum angular velocity of the adduction of the shoulder; MER = maximum external rotation of the shoulder; DRL = disc release. CCW = Counterclockwise. CW = Clockwise. Statistical significance was set at $p < 0.05$.

Maximal angular velocity of trunk rotation, horizontal shoulder adduction and shoulder adduction occurred before maximum external rotation of the shoulder (Figure 2). Maximal angular velocity of shoulder adduction occurred before maximal angular velocity of CCW trunk rotation, anterior trunk tilt and medial trunk tilt ($p < 0.05$). Maximal angular velocity of CCW trunk rotation occurred at a similar time to maximal angular velocity of horizontal shoulder abduction ($p > 0.05$).

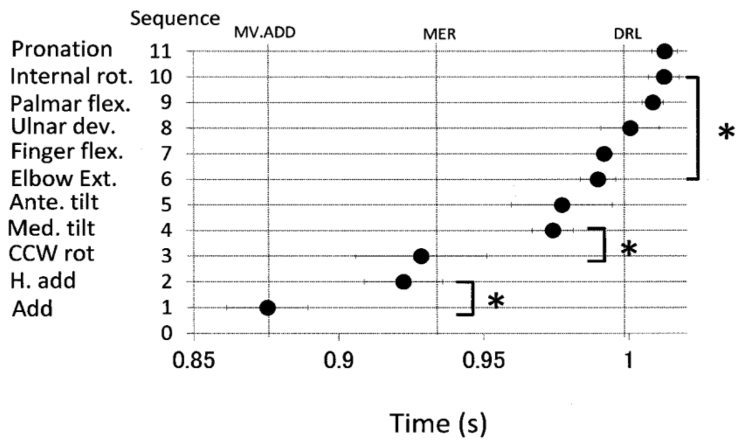

Figure 2: The timing of maximal angular velocity about each axis of the shoulder, elbow, radio-ulnar, wrist, and third metacarpal joints. Error bars represents standard deviation of the time of maximal angular velocity of each joint of all participants. *Significant difference (p < 0.05) between each joint.

DISCUSSION: Our results show that the timing of maximal linear and angular joint velocity did not occur in a proximal-to-distal sequence. The maximal linear velocity of the elbow occurred earlier than that of the shoulder, and the maximal adduction velocity of the shoulder occurred earlier than the maximal angular velocity of CW rotation, medial tilt and anterior tilt of the trunk. However, the magnitude of maximal linear velocity increased from the proximal (shoulder) to distal (disc).

Extreme external rotation of the shoulder during the throwing motion is provided by earlier and more extreme acceleration of the shoulder and elbow than of the wrist and a projectile (Feltnar and Dapena 1986). The results of the present study suggest that shoulder adduction may be important in determining the linear velocity of the elbow in the direction of the throw. At the time of MV-ADD, the trunk was turned to the right (X_G direction) and tilted to the right. When in a standing posture, adduction of the shoulder moves the upper arm in the direction perpendicular to the ground. When the trunk is turned and tilted to the right posture in this study, adduction of the shoulder moves the elbow in the direction of the throw. In the present study, all participants had shoulder abduction of approximately 90° at the instant of MABD. They could have had greater angle of shoulder abduction to further increase the linear velocity of the elbow. Moreover, maximal angular velocity of CCW trunk rotation, horizontal shoulder adduction and shoulder adduction occurred before MER. They could work together with adduction of the shoulder to increase the linear velocity of the elbow. Therefore, adduction of the shoulder could have contributed to the increased external rotation of the shoulder.

The shoulder abduction angle at the instant of maximum abduction of the shoulder was approximately 90°, and maximum angular velocity of adduction of the shoulder occurred between the instant of maximum abduction angle and maximum external rotation angle of the shoulder. Subsequently, from maximum external rotation of the shoulder until disc release, shoulder adduction/abduction was maintained at approximately 60°. The skilled was internally and extremely rotated the shoulder in this phase. The skilled throwers who participated in this experiment could keep the adduction/abduction angle constant to enable smooth acceleration of the disc during the internal rotation phase of the throw. In the sidearm throwing motion studied here, shoulder adduction could be one of factors for increasing the external rotation of the shoulder from MABD until MER, and play a role in ensuring the optimal position of the disc before MER to enable smooth acceleration of the disc during the acceleration phase.

CONCLUSION: During a sidearm throw of a disc by skilled throwers, the magnitude of maximal linear joint velocity increased from proximal to distal. However, the timing of maximal linear joint velocity did not occur in a proximal-to-distal sequence. The maximal linear velocity of the elbow occurred before the maximal linear velocity of the shoulder. This deviation from the proximal-to-distal sequence in skilled throwers could be due to the timing of maximal angular velocity of shoulder adduction which occurred earlier than the maximum angular velocity of CCW trunk rotation, left trunk tilt and forward trunk tilt. This deviation from the proximal-to-distal sequence in the maximum linear and angular velocities of the throwing arm could be particular to the sidearm throwing motion performed. In conclusion, coaches should not try to enforce a proximal-to-distal sequence in training of the sidearm throwing motion of a disc for distance.

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