KINEMATIC AND TECHNICAL FACTORS FOR ACCELERATION OF WHOLE BODY IN ROTATIONAL SHOT PUT TECHNIQUE

Tadahiko Kato[1], Hirofumi Kintaka[2], Yoshihisa Urita[2], Akira Maeda[3]

[1] Graduate school of Physical Education, National Institute of Fitness and Sports in Kanoya, Kanoya, Japan
[2] Coaching Science of Sports and Budo, National Institute of Fitness and Sports in Kanoya, Kanoya, Japan
[3] Sports and Life Science, National Institute of Fitness and Sports in Kanoya, Kanoya, Japan

The aim of this study was to gain the knowledge about kinematic and technical parameters required for acceleration of whole body in rotational shot put technique, using three-dimensional motion analysis. 12 male shot putters participated this study. From the results, linear momentum during double support phase (DSP) (r = 0.64, 0.79, p < 0.05, 0.01) and angular momentum during flight phase (FP) and 2nd single support phase (SSP2) (r = 0.58-0.72, p < 0.05, 0.01) were closely related with throwing record, and these parameters would indicate the acceleration of whole body. In addition, path length of center of gravity at DSP related with linear momentum (r = 0.75, p < 0.01). And the velocity of right toe, right elbow and left heel were closely related with angular momentum during FP and second single support phase (SSP2). These results can be concluded that enhancement these parametars will be effective techniques for acceleration of whole body.

KEY WORDS: athletics, three-dimentional motion analysis, momentum

INTRODUCTION: The shot put is an athletic event and the mass of a shot is 7.26 kg for men's event. Rotational shot put technique is one of the throwing style, and the event of the motion can generally be divided into five phases (Figure 1) (Coh and Stuhec, 2005). The most important factor required for throwing record is initial velocity of the shot at Rel (Luhtanen, 1997). Shibukawa et al. (1968) described that the importance to raise the inflowed energy into the shot for increaseing the velocity. Shibukawa et al. (1968) also suggested that thrower must raise the generated energy in the body for raising the inflowed energy into the shot. In the rotational shot put technique, shot velocity decreases during FP and SSP2 (bartonietz, 1997: Lanka, 2000: Ohyama et al., 2008). However, whole body momentum is gained or maintained (Ohyama et al, 2008). Thus, Ohyama et al. (2008) indicated that the acceleration of athlete-shot system is the key factor ensuring the source of energy for delivering the shot. These findings suggested that how to gain the body momentum for inflowing the energy into the shot are important in the rotational shot put technique. Nevertheless, it's not clear that which timing or what kind of kinematic parameter is important in rotationl style shot put. It is also necessary to verify the technical parameters which affect the kinematics parameters.

Therefore, the purpose of this study was to gain the knowledge about kinematic and technical parameters required for acceleration of whole body in rotational shot put technique.

METHODS: The subjects were 12 male shot putters (age: 22.08 ± 1.44 years; height: 1.79 ± 0.91 m; body mass: 113.75 ± 9.14 kg; personal record: 15.63 ± 1.51 m), and subjects were all right-handed thrower. The subjects' personal records ranged from a novice level to an elite level in Japan. The experiments were conducted in the competitions. Two or three digital video cameras (HDR-CX675, SONY, Tokyo, Japan) were used to record the throwing motion of each subject at 60 frames/s with a shutter speed of 1/1000 s. The experiments were approved by the Ethics Review Committee of National Institute of Fitness and Sports in KANOYA. The shot and 23 endpoints of each body segment were manually digitised and reconstructed using Frame-Dias V (DKH, Tokyo, Japan). The three-dimentional DLT method

was applied to collect coordinate data of the shot and endpoints of 14 body segments. The coordinate data were smoothed with a Butter worth digital filter: the cut-off frequencies ranging from 3 to 9 Hz. To calculate the linear momentum and angular momentum, the location of the center of gravity (CG) and moment of inertia for each body segment were estimated from the body segment inertia parameters developed by Ae et al. (1996). linear momentum was caluculated from the product of bodymass and the velocity of CG. Angular momentum was calculatede with the method of Dapena (1978), and in this study, angular momentum was calculated around vertical axis of CG. As the technical parameters, some parameters about velocity of endpoints were calculated. The relationships among the various parameters were quantified using linear correlation techniques with the significance level for statistical analysis set at $p < 0.05$.

Double Support Phase (DSP)	1st Single Support Phase (SSP1)	Flight Phase (FP)	2nd Single Support Phase (SSP2)	Delivery Phase (DVP)

PS (Preparation Swing)	Roff (Right foot takeoff)	Loff (Left foot takeoff)	Ron (Right foot touchdown)	Lon (Left foot touchdown)	Rel (Release)
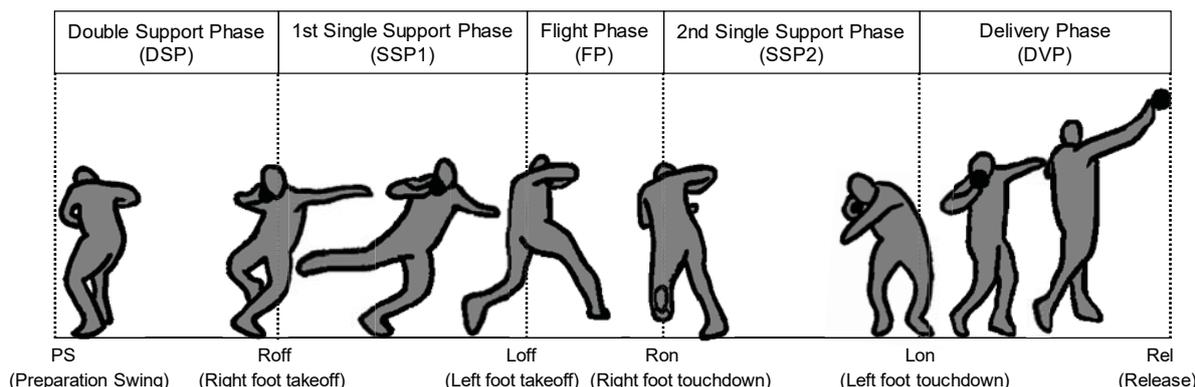
Figure1: Defined events and motion phases of rotational shot put technique.

RESULTS: Table 1 shows the relationships between throwing record and linear momentum before Lon: value of each event and maximum value of each phase. The value of linear momentum at Roff (r = 0.64, p < 0.05) and the maximum value at DSP (r = 0.79, p < 0.01) were significantly correlated with throwing record.

Table 1
Correlation coefficients between throwing record and linear momentum.

	Event (value at event)					Phase (maximum value)			
	PS	Roff	Loff	Ron	Lon	DSP	SSP1	FP	SSP2
r	0.092	0.64	0.53	0.55	0.51	0.79	0.57	0.50	0.55
p	n.s.	*	n.s.	0.066	n.s.	**	0.053	n.s.	0.063

* p < 0.05, ** p < 0.01

Figure 2 shows the relationships between the maximum value of linear momentum and CG path length at DSP. Synthesized and horizontal CG path length were significantly correlated with linear momentum (r = 0.78, 0.83, p < 0.01). Vertical CG path length was not correlated with linear momentum.
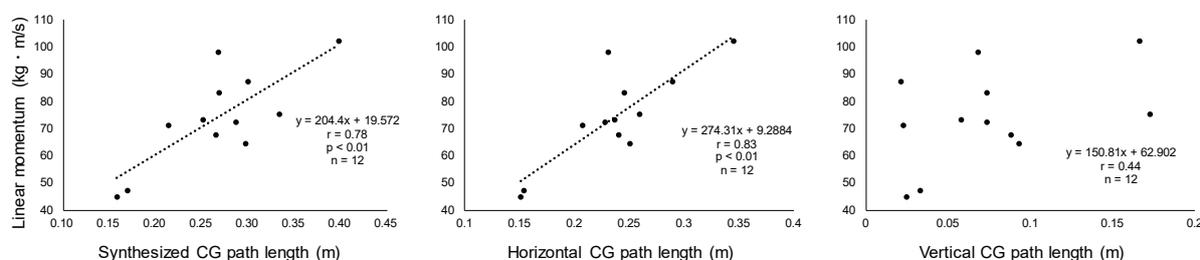
Figure 2 Relationships between linear momentum and CG path length at DSP

Table 2 shows the relationship between throwing record and angular momentum. The value of angular momentum at Loff, Ron and Lon (r = 0.58 – 0.72, p < 0.05, 0.01), and the maximum value at FP (r = 0.69, p < 0.05) were significantly correlated with throwing record.

Table 2
Correlation coefficients between throwing record and angular momentum.

	Event (value at event)					Phase (maximum value)			
	PS	Roff	Loff	Ron	Lon	DSP	SSP1	FP	SSP2
r	-0.16	0.26	0.61	0.72	0.58	0.26	0.44	0.69	0.63
p	n.s.	n.s.	*	**	*	n.s.	n.s.	*	*

$* p < 0.05, ** p < 0.01$

Table 3 shows the relationships between value of angular momentum and velocity of some endpoints before and after FP and SSP2. The maximum velocity of right toe during SSP1 and FP was correlated with The maximum value of angular momentum at FP ($r = 0.58$, $p < 0.05$). The maximum velocity of right elbow during SSP1 and FP was correlated with the value of angular momentum at Loff ($r = 0.66$, $p < 0.05$) and the maximum value at FP ($r = 0.58$, $p < 0.05$). The maximum velocity of left heel during FP and SSP2 was correlated with the value of angular momentum at Loff and Ron ($r = 0.77$, 0.77, $p < 0.01$) and the maximum value of angular momentum at FP and SSP2 ($r = 0.81$, 0.61 $p < 0.01$).

Table 3
Correlation coefficients between angular momentum and velocity of endpoints before and after FP and SSP2.

		Max. velocity of right toe (SSP1-FP)	Max. velocity of right elbow (SSP1-FP)	Max. velocity of left hand (SSP1-FP)	Max. velocity of left heel (FP-SSP2)
Angular momentum	Loff	0.55	0.66*	-0.01	0.77**
	FP (max.)	0.58*	0.58*	0.01	0.81**
	Ron	0.54	0.50	0.12	0.77**
	SSP2 (max.)	0.15	0.37	0.25	0.61**
	Lon	0.56	0.001	0.35	0.55

$* p < 0.05, ** p < 0.01$

DISCUSSION: In this study, maximum value of linear momentum at DSP was correlated with throwing record, and linear momentum at DSP was correlatede with CG path length. In discus throw, thrower performs similar motion at DSP. Hay (1985) discribed that it is important for the ultimate success of the throw to adjust the position of the left foot by rotating it toward the throwing direction with a shifting of the CG to the left and over the left foot. Thus, Maeda et al. (2016) suggested that the dynamic shifting of CG to the left would be effective to create a greater amount of momentum at DSP in discus throw. As in the case of discus throw, thrower also creates linear momentum by the shifting of CG to left in rotational shot put technique. And increase in the length of horizontal movement of CG would be effective to gain the linear momentum.

The value of angular momentum Loff, Ron and Lon and the maximum value at FP were correlated with throwing record. Ohyama et al. (2008) indicated that the acceleration of athlete-shot system at FP and SSP2 is the key factor ensuring the source of energy for delivering the shot. Lipovesk et al (2011) showed the importance of the acceleration path length of the shot at DSP, and effective use of angular momentum makes the path length widely. Therefore, the results of this study suggested that the value of angular momentum at Loff, Ron and Lon and the maximum value at FP would be the kinematic parameters to ovserve the accelertion of athlete-shot system. And higher level thrower created a greater amount of angular momentum before Lon, and would use it effective for acceleration of the shot at DVP.

Genellary, right-handed thrower swings their right elbow and right leg toward the throwing direction during SSP1 and FP. From our results, higher velocity of right elbow and right toe during SSP1 and FP would be effective to create angular momentum. Thus, these motions were some of critical foctors to accelerate whole body at FP. Ohyama et al. (2008) showed an example of angular momentum about world level thrower. His angular momentum increased during FP and SSP2. Therefore, Ohyama et al. (2008) suggested that it closely

related to the intensive swing of the left leg. The velocity of left heel would indicate the swing of left leg, and high velocity of left heel during FP and SSP2 would be important to accelerate a whole body during SSP2.

CONCLUSION: The results of the present study show: (1) linear momentum at Roff and maximum value at DSP were significantly correlated with throwing record; (2) linear momentum at DSP was closely correlated with CG path length at DSP; (3) angular momentum at Loff, Ron, Lon and maximum value at FP were significantly correlated with throwing record; (4) maximum velocity of right toe and right elbow during SSP1 and FP were significantly correlated with angular momentum; (5) maximum velocity of left heel during FP and SSP2 was significantly correlated with angular momentum. These result suggest that the technical factors for acceleration of whole body are: (1) increase in the horizontal path length of CG at DSP. (2) Swinging the right elbow and right toe toward the throwing direction with higher velocity during SSP1 and FP. (3) Swinging the Left foot with higher velocity during FP and SSP2.

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