GROUND REACTION FORCE OF ROTATIONAL SHOT PUT – CASE STUDY

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The purpose of this study was to investigate the kinetic variables of two legs during rotational shot put. Three male rotational shot putters served as subjects. Two force platforms were synchronized to collect the data. The kinetic variables of right leg which had the trend of decrease with better performance were the maximal vertical force, rate of force development of maximal propulsive force, impulse of horizontal and vertical force during braking phase, total impulse of horizontal and vertical force. The kinetic variables of left leg which had the trend of increase with better performance were the total impulse of vertical and horizontal force. The smaller braking and greater propulsive time of the right leg, and the greater braking and vertical thrust of the left leg would helpful for better performances.

KEY WORDS: biomechanics, kinetics, lower limb.

INTRODUCTION:

During shot-putting, shot putters' legs drove the body to the throwing direction and forcefully supported and stretched at thrust. The power of shot-putting was mainly produced by legs (Dessureault, 1978). Shot-putting was a speed-power throwing movement. The vigorous push of legs speeded up the movement and gave the body a powerful lifting. Furthermore, shot-put technique emphasized the fluent connections and the speed rhythm of the motion. The appropriate support of legs made the movement smooth and kept the body balanced. (Dessureault, 1978; Luhtanen, Blomqvist, & Vanttiene, 1997). The strength, speed-power, agility and coordination of shot putters` legs were needed in shot-put training programs (Palm, 1990, 1991). The legs played a crucial part in shot-putting. Reviewing the references, Dessureault (1978) and Zatsiorsky, Lanka & Shalmanov (1981) had studied the kinetic variables of gliding shot put. Both of them found that there were significant correlations between some variables and performance. Bartonietz (1994) had compared the difference in kinetic variables between rotational and gliding shot put. Rotational shot put is a main stream event nowadays. Coaches and shot putters were aware of the importance of lower limbs during throwing. However, few researchers were working on the kinetic analyses of lower limbs of rotational shot put. The purpose of this study was to investigate the kinetic variables of two legs during rotational shot put.

METHODS:

Three male college shot putters (S1- age: 23 years, height: 194 cm, weight: 133 kg; S2- age: 25 years, height: 175 cm, weight: 128 kg; S3- age: 22 years, height: 167 cm, weight: 72 kg.) volunteered to be the subjects in this study. Each subject provided their informed consents prior to the participation. The protocol was approved by the Taipei Medical University Ethical Committee. All subjects had no injury during the time of the study and were right-handed throwers. A specific designed shot put field where two force plateforms (60 cm × 40 cm, 1250 Hz; Kistler, Switzerland) were mounted in the center and front of the shot-put circle was set. Kwon GRF (Visol Inc., Seoul, Korea) was used to collect and analyze the kinetic data. Subjects practiced a 30-minute warm-up and two practice trials. They were asked to perform as an official game and do their best. Each subject performed six throws just as an official game. There was five-minute break between throws. S1, S2 and S3 distributed three, one, and four trials, respectively, which the ground reaction force (GRF) were successfully collected. The performance with the maximum horizontal displacement of the shot for each subject was analyzed. The time of the supporting phases of two legs were normalized to percentage (100%). The GRF was normalized to body weight (BW). The rate of force development was the ratio of GRF to it’s time (△F/△T). The impulse was the integral of GRF and time ($I_{(j)} = \int_{t_{landing}}^{t_{takeoff}} Fy_{(j)} dt$; unit: Ns). The impulse was normalized to body weight (Ns/kg).

RESULTS:
The measured displacements of the shot for each subject were S1:16.86 m, S2:15.60 m, S3:12.88 m, respectively. The curve of horizontal GRF of the figure was divided into two phases, braking and propulsive phases, according to the backward and forward of the horizontal GRF respectively. Figure 1 showed the GRF of right leg. The figure showed the braking force came first following by propulsive force during right leg supporting. The maximal braking force was greater than the maximal propulsive force except for S2 (Table 1). The maximal vertical force was reached close to the braking force turning to propulsive force. Table 2 showed that the impulses of horizontal forces during braking phase were greater than those during propulsive phase. The total impulse of horizontal force was negative which meant the braking. The impulses of vertical forces during propulsive phase were greater than those during braking phase except for S3. In terms of time, the time of braking phase was greater than that of propulsive phase except for S1. The kinetic variables of right leg which had the trend of decrease with better performance were the maximal vertical force, rate of force development of maximal propulsive force, impulse of horizontal and vertical force during braking phase, total impulse of horizontal and vertical force. The kinetic variables of right leg which had the trend of increase with better performance were the total time of propulsive phase.

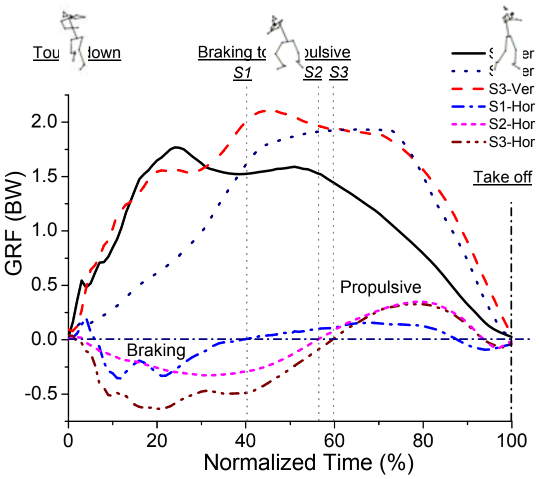

Figure 1: GRF of right leg

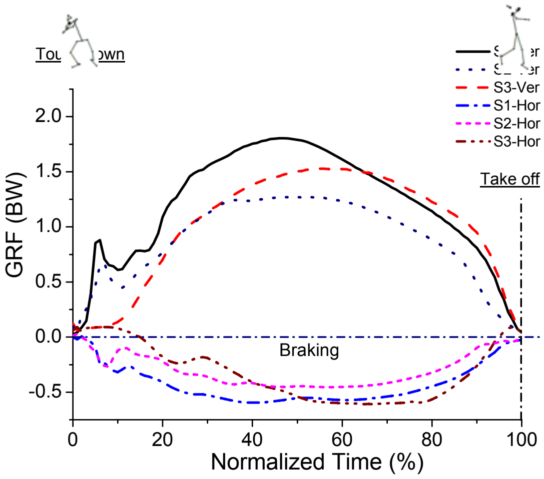

Figure 2: GRF of left leg

Table 1: The GRF and rate of force development of right leg

Variable	S1	S2	S3
Normalized maximal vertical force (BW)	1.77	1.94	2.11
Time to maximal vertical force (from touch down) (s)	0.073	0.246	0.159
Normalized maximal propulsive force (BW)	0.16	0.35	0.33
Time to maximal propulsive force (from touch down) (s)	0.202	0.312	0.279
Normalized maximal braking force (BW)	-0.37	-0.33	-0.64
Time to maximal braking force (from touch down) (s)	0.034	0.117	0.073
Rate of force development of maximal vertical force (BW/s)	24.25	7.87	13.27
Rate of force development of maximal propulsive force (BW/s)	0.78	1.12	1.20

Figure 2 showed that most horizontal GRF during the left leg supporting was the braking force. The time of the maximal braking force produced was close to that of the maximal vertical force produced (Table 3). After comparing the right leg and left leg, we found that the maximal braking force and horizontal impulse of the left leg was greater than that of the right leg except for S3. The maximal vertical force of vertical force of the left leg was smaller than that of the right leg except for S1. The total impulse of vertical force of the left leg was smaller than that of the right leg. The kinetic variables of left leg which had the trend of increase with better performance were the total impulse of vertical and horizontal force.

Table 2: The impulse and time of each phase of right leg

Variable	S1	S2	S3
Impulse of horizontal force during braking phase (Ns/kg)	-0.17	-0.44	-0.83
Impulse of horizontal force during propulsive phase (Ns/kg)	0.11	0.31	0.25
Impulse of vertical force during braking phase (Ns/kg)	1.45	2.18	3.22
Impulse of vertical force during propulsive phase (Ns/kg)	1.79	2.23	2.07
Total time of braking phase (s)	0.117	0.221	0.214
Total time of propulsive phase (s)	0.180	0.172	0.146
Total impulse of horizontal force (Ns/kg)	-0.05	-0.13	-0.58
Total impulse of vertical force (Ns/kg)	3.24	4.44	5.15
Total time of right leg support (s)	0.297	0.393	0.360

Table 3: The GRF, rate of force development, impulse and time of left leg

Variable	S1	S2	S3
Normalized maximal vertical force (BW)	1.81	1.27	1.54
Time to maximal vertical force (from touchdown) (s)	0.092	0.107	0.093
Normalized maximal braking force (BW)	-0.60	-0.46	-0.61
Time to maximal braking force (from touchdown) (s)	0.079	0.117	0.111
Rate of force development of maximal vertical force (BW/s)	19.65	11.89	16.53
Total impulse of vertical force (Ns/kg)	2.32	1.78	1.64
Total impulse of horizontal force (Ns/kg)	-0.82	-0.60	-0.51
Total time of left leg support (s)	0.199	0.207	0.166

DISCUSSION:

In the rotational shot put, the right leg stepped onto the center part of the circle and supported the whole body weight; meanwhile, shot putters continued the rotating movement and gradually transited the body center of mass from the back to the front with the supporting point of the right leg. In this study, we found that the maximal vertical GRF of the right leg was reached close to the turning point of the braking to propulsive during the right leg supporting. From the filmed data, the turning point was about the left leg landing which meant shot putter was going into two legs supporting. The result showed that better shot putter's right leg produced lower maximal vertical GRF and impulse of vertical GRF which meant shot putters should not land too hard at right leg touchdown. The amplitudes of the right leg vertical GRF of S1 and S2 had minor peak just after touchdown. The amplitudes were like these of running (Cavanagh and Lafortune, 1980). In this study, better shot putter's right leg produced lower braking force and impulse which were features for efficient running. As the left leg landed, the right leg was pushed upward to lift the body. However, the right leg total impulse of horizontal force was negative which meant it was still doing the braking during supporting. The smaller braking of the right leg may make the better performance. The propulsive phase followed the braking phase. In this study, the longer propulsive time may be helpful for the better performance. We suggested that shot putters should not take off too high during flying phase and land softly.

Around the turning point of the braking to propulsive during the right leg supporting, the left leg was landing. The left leg was executing the braking by the time the right leg was executing the propulsive. The body did not move forward in case the foul mainly depending on the forceful braking of the left leg. In this study, the better shot putter produced greater

impulses of vertical and horizontal force of the left leg. The left leg total impulse of horizontal force was negative which meant it was doing the braking during supporting. Although the braking of the left leg decelerated the body movement, it made the better performance. The function of braking of the left leg was important. Furthermore, the left leg also pushed upward to lift the body to transit the horizontal movement to vertical movement.
We had only three subjects in the study. Because few shot putters used the rotational technique in Taiwan. We can just show the individual trial data of three shot putters. Further study could recruit more subjects to perform statistical analysis to figure out the correlation between kinetic variables and performance. The force plateforms were too small. It was hard to correctly step on the plateforms for every shot putter. Using larger force plateform would be helpful for collecting the GRF data.

CONCLUSION:
This study showed kinetic variables of two legs during rotational shot put. The right leg showed the pattern of braking to propulsive while the left leg was just showing the braking. During the transition of rotational shot put, the right leg should decrease the braking impulse and vertical GRF. During the thrust of rotational shot put, the right leg should increase the propulsive time while the left leg should increase the braking impulse and vertical impulse.

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