KINEMATIC ANALYSIS OF SHOT PUT IN ELITE ATHLETES – A CASE STUDY

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This paper presented the application of biomechanics in the shot put. Three elite shot-putters was video recorded. By planar analysis, the following kinematic data have been discussed: (1) the loss of distance in performances, (2) the swinging span of the leg, (3) the height of the shot before the last effort, (4) the waving manner of the swinging arm, and (5) the influence of the differences between the velocity angle of the released shot and its optimum angle. The effects of the measured values of above parameters on performances and their mechanic causes were analyzed. The results of this study provided the information for improvement of performance in athletes.

KEY WORDS: shot-put, kinematic, video filming

INTRODUCTION: The purpose of this study was to analyze and solve the problems in shot putting practice, by applying the principles and methods of biomechanics and through kinematics, in order to find the factors influencing performance Besides the strength and physical ability, the skills and techniques in performances also play important roles in shot putting. Three elite shot-putters from Jiangsu province were analyzed by digitized video in this study. Some of characteristics of kinematics and their influence on performances were discussed. Finally, diagnostic suggestions were offered to athletes and coaches in the training.

METHODS: Three elite shot-putters served as the subjects for this study. They are Panying Hu (female, 1977, 175cm, 85kg), Zhenbao Hui (male, 1982, 185cm, 125kg) and Tao Ren (male, 1980, 186cm, 120kg), in the brackets are sex, birthday, body height and body weight.
A video camera was positioned at the right side of the shot-putters, on the side of the throwing arm. The video camera model: Panasonic AG-DP200, PAL mode, with field frequency of 50Hz, was used. The distance from camera lens to the throwing plane was 18m. The principal optic axis of the camera was perpendicular to the throwing plane and the point of intersection was at the front edge of the throwing circle. The lens was 1.2m height from the ground. Planar analyses were adopted and the origin point was selected at the front end of the long diameter of throwing ellipse. In the video image, the circle was a flat ellipse. The X axis orientation was in accordance with the forward direction. The raw data points were screened using a Butterworth digital filter with 8 Hz cutoff frequency. The MATUI model (Japan) was adopted to digitize the performance. The six throws for each shot-putters were recorded in turn by the video camera.

RESULTS AND DISCUSSION: In Table1, the “Order” is the order of six throws for each shot-putter. The “Px” was the X coordinates of the shot as it just released from hand. It was defined as the distance between the position of shot and the front edge of throwing circle in horizontal direction (shown in Figure 1). The “Span” was defined as the distance measured from initial position of the right toe to left toe just before the glissade of right foot (see Figure 2). The “Result” was measured by tape-line in the field of shot put after each throw. The “Distance” was the actual distance the shot-putter had thrown, which was identified as the “Result” plus the absolute value of “Px”. “Angle” was the shot velocity direction angle measured from horizontal direction as the shot released from hand. “O-Angle” was the optimized shot velocity direction angle calculated theoretically by the test values of the velocity and the height of the shot when released. The ” Velocity” and “Height” were the test values of the velocity and the height of the shot when released.

Table 1 Selected kinematic variables of three athletes in shut putting

Name Height	Order	Px	Span	Result	Distance	Angle	O-Angle	Velocity	
		cm	cm	m	m	(°)	(°)	cm/s	cm
Panying Hu	1	-12	185	15.70	15.82	35.3	39.9	11.59	2.00
	2	-16	186	15.66	15.82	34.0	40.1	11.68	1.95
	3	-22	185	15.40	15.62	40.7	39.6	11.32	1.99
	4	-21	190	15.80	16.01	38.2	39.7	11.42	2.01
	5	-15	192	16.04	16.19	35.2	40.1	11.70	1.99
	6	-14	188	15.55	15.69	40.8	39.8	11.58	2.02
	Ave.	-16.7±4.0	187.7 ±2.9	15.69±0.22	15.86±0.21	37.4±3.0	39.9±0.2	11.55±0.15	1.99±0.02
Zhenbao Hui	1	0	168	15.40	15.40	38.2	38.7	11.07	2.14
	2	-6	174	15.65	15.71	34.4	39.2	11.36	2.10
	3	-2	172	15.59	15.61	34.4	39.7	11.49	2.10
	4	-9	178	15.74	15.83	36.2	39.4	11.60	2.14
	5	-1	176	15.50	15.51	34.3	39.0	11.33	2.16
	6	-2	175	15.86	15.88	37.1	38.6	11.07	2.16
	Ave.	-3.3± 3.4	173.8 ±3.5	15.62 ±0.17	15.66±0.19	35.8±1.7	39.1±0.4	11.32±0.22	2.13±0.03
Tao Ren	1	-7	182	16.05	16.12	37.4	39.3	11.44	2.12
	2	-6	185	16.12	16.18	35.4	39.3	11.44	2.11
	3	-2	184	16.20	16.22	35.1	39.3	11.35	2.09
	4	-5	185	16.10	16.15	36.1	39.5	11.42	2.06
	5	-5	183	16.39	16.44	37.4	39.2	11.33	2.10
	6	-7	184	16.40	16.47	37.8	39.7	11.63	2.06
	Ave	-5.3±1.9	183.8±1.2	16.21 ±0.15	16.26±0.15	36.5±1.2	39.4±0.2	11.44±0.11	2.09 ±0.03

The horizontal position of shot just released. In Table 1 The "Px" was the X position of shot as it was released from throwing hand, the negative indicates that the position of the shot was located behind the front edge of the throwing circle when the shot was released. Compared to the test values of "Px" form Table 1, the differences were found between Panying Hu and the others, The "Px" for Panying Hu was bigger than that for Zhebao Hui and Tao Ren. The lost distance in result for Panying Hu was about 16.7 ± 4.0cm in average. The question arose as to the cause of the discrepancy. Two aspects could be explained in biomechanical terms. The first is due to individual and habitual action structures, as the shot-putter takes off, making a projectile motion when throwing, and needs a distance to balance the body. Secondly, after releasing the shot, there is still momentum forward on the body. To counteract momentum and to balance the body, the distance was needed. In both aspects, it could be seen that an appropriate distance was necessary to stop the body. After all, the forward momentum and velocity of body can contribute to the velocity of the shot. However, the velocity of shot mainly comes from the effort of the throwing arm, It was limited to obtain velocity of shot by increasing the velocity of body. If the strength of throwing arm was not sufficient, the forward momentum of the body could not be counteracted by a last effort of throwing arm. The distance that is required to balance the body must be longer. In addition, the benefits from the body velocity couldn't compensate the loss of the distance as a result.

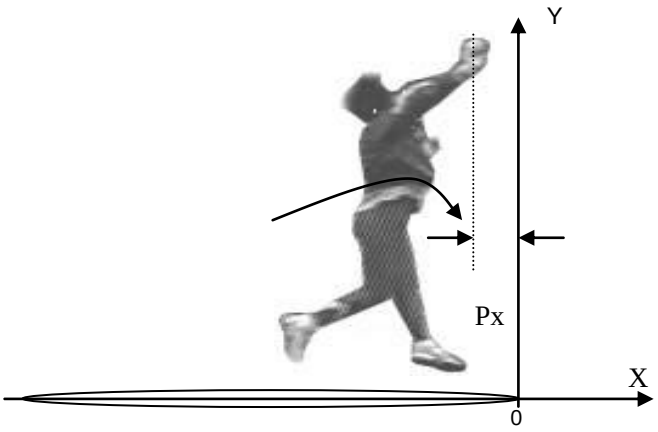

Figure 1 - The coordinate system selected and the loss of result Px.

Three shot-putters in this test are all elite. The distances that are required to stop the

momentum for Panying Hu were longer than that of the other two shot-putters. The cause for this might be the weaker arm strength of the female. She couldn't reduce momentum utilizing the counter-force of the force putting the shot. Therefore, a longer distance was needed to stop the momentum. Authors of this paper think that in the case of equivalent velocity of shot, adequate utilization of the angular momentum of body would reduce the distance of balance.

The span of the leg swinging before the glissade. The "Span" was defined in the context above (see Figure 2). Comparing the "Span" and "Distance" in Table 1 for six throws, it could be found that these two variables had positive correlation. The span for Panying Hu varied from 184.7cm to 191.5cm, the scope was 6.7cm. The throwing distances varied from 15.62m to 16.19m, and showed a significant correlation between the span and the throwing distance ($r=0.84$, $p<0.05$). The span for Zhenbao Hui varied from 167.8cm to 178..4cm, and the scope was 10.6cm. The throwing distances varied from 15.40m to 15.88m, and showed moderate correlation between the span and the throwing distance ($r=0.66$, $p<0.05$). The performances of Tao Ren were very similar in six throws. Except for the first throw, the span varied in a narrow scope (<2cm), near to the value of the error of the test. There was nothing to be gained in doing correlation analysis in so narrow a scope.

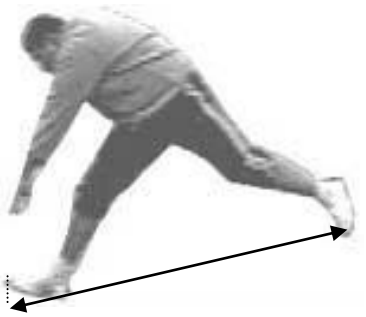

Figure 2 - The span between left toe and right toe just before glissade.

By increasing the span of the leg swinging before glissade, it was determined that forward momentum of the body would increase. As a result, the right leg would bend more easily and quickly. A good attitude of the body for last effort would be formed after the glissade with small angle of knee, in a lower position of the shot.

In the six throws performed by every shot-putter, the correlation between span and throwing distance was typical for Panying Hu, The performances of Zhenbao Hui varied widely. He was the youngest of them. It was also perhaps a result of years of training. Contrarily, the performances of Tao Ren were very consistent. The differences between the six throws were very small. It is difficult to find any one factor that would affect the overall result of the performance. Only by comparing the kinematics data of one athlete with that of others, would it be possible to determine errors.

The span relative to body height for Panying Hu, Zhenbao Hui and Tao Ren were 187.5± 2.9/175×100=107.1%±1.5%,173.8±3.5/185×100=93.8%±2.0%,183.8±1.2/186×100=98.8%± 1.0%. The largest relative value was that of Panying Hu, The smallest relative value was that of Zhenbao Hui, It probably indicates that the female shot-putters had more flexibility.

The height of the shot before the last effort. As shown in Figure 3, before last effort, the height of shot for Panying Hu, Zhenbao Hui and Tao Ren was 115±1.7cm,105±1.7cm,98± 2.1cm. The shot already had a certain height as Panying Hu did the last effort. These values

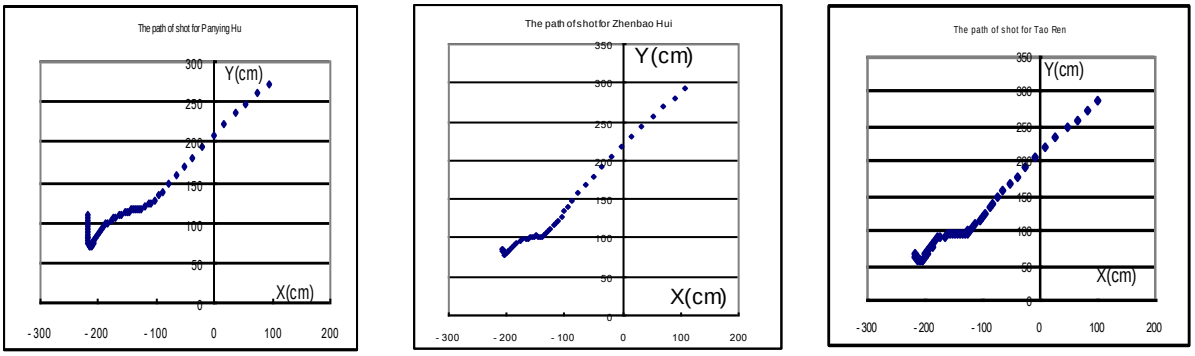

Figure 3 - The path of the shot for Panying Hu, Zhenbao Hui and Tao Ren.

relative to the body height were 115/175×100=65.9%±0.9%, 105/185×100=57.2%±0.9%, 98/186×100=52.7%±1.1% respectively. The body height of Panying Hu was lower, but the shot was higher before last effort. So the range for arm to work was short. This does not produce good results. However, the initial velocity of the shot was higher for this athlete, that s to say, the velocity of body of Panying Hu was higher than the others. In addition, the lighter shot for women might make a slight difference in shot putting style comparing it with that for a man.

The waving manner of swinging arm. As shown in Figure 4, there was a considerable difference in the waving manner of swinging arm between Tao Ren and Panying Hu. During the foot touchdown, the arm drew an upward arc for both Tao Ren and Zhenbao Hui. This resulted in a forward angular momentum, the axis of rotation approach frontal axis. In same phase, the arm drew a forward arc for Panying Hu. This athlete achieved a horizontal angular momentum, the axis of rotation approached the vertical axis. During takeoff, Zhenbao Hui and Tao Ren bent their swinging arms to the body, However, Panying Hu spread her arm away from her body. This prevented utilization of the angular momentum required to speed up the shot. The influence of swinging arm had been reported by Chaojun Wang (1998) in the comparative research on the effect of the swinging arm in last shot putting effort, (See references below), Effective swinging of arm could benefits the result.

Using biomechanical analysis during touchdown of the foot, the swinging arm should be fully outspread and swing rapidly, and during takeoff of the body, the arm should bend to the body. In this test, the swinging arms of Hu and Tao were stretched fully and swinging rapidly. In contrast, Hui's throwing arm showed insufficient stretch.

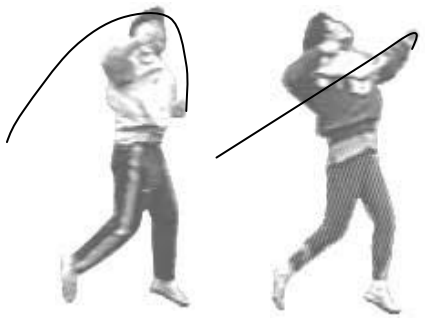

Figure 4 - The waving manner of the swinging.

The approximation of the optimum velocity angle (α). The approximation of the optimum velocity angle (α) of the released shot was calculated by the following formula with the velocity (V_0) and height (H) of the released shot. Comparing the actual angle with the optimum angle in Table1, it was found that the actual angle was smaller for all these shot-putters of Jiangsu team. Calculation shows the releasing angles of ±5°from the optimum angle would reduce the throwing distance by about 20cm. With the increase of the releasing velocity, the

$$\sin^2\alpha = \frac{V_0 + \sqrt{V_0^2 - 4gH}}{4V_0}$$

optimum angle would increase. Therefore, in competition the larger angle must be emphasized.

CONCLUSION: In order to decrease the loss of distance in the shot putt, the horizontal distance should be reduced between the released shot and the front edge of throwing circle. The distance could be reduced, by the counter-force of propulsion of the shot. The forward momentum of the body could be also counteracted by the last effort of throwing. Therefore the strength of the arm not only is a question of the capacity but also is a question of the technique. The distance also could be reduced by effective swinging arm to utilize adequate angular momentum of body. In this test, the distances were longer for Panying Hu and shorter for the others.

The larger span of the leg swinging can increase forward momentum and velocity of the body, making the right leg bend quickly and provide good support for the last effort. This was shown typically from the data of Panying Hu in this study.

After the glissade of right leg, the lower position of the shot could provide a longer work range for throwing arm. The positions were higher for Panying Hu in this test. So the work range of the throwing arm were shorter. However, this athlete had good continuity of velocity in the process of shot putting.

There exist evident differences in the motion of waving arm between the tested male and female shot putters. The male's swinging plane tends to be vertical to the ground, while the female's tends to be horizontal. The correct motion is as follows: fully stretch the swinging arm and swing quickly while feet touch the ground, then bend the arm to the body as close as possible during take-off.

Conversely, the tested shot-putters should pay special attention to the enlargement of the releasing angle.

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