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Comparison of shot put motion among male athletes with various competing levels

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ABSTRACT

The purpose of this study was to compare the shot put motion among male athletes using glide technique with various competing levels. Subjects were 24 male shot putters with glide technique during finals of three international athletic meets. The putting motions were recorded and analyzed using three dimensional motion analysis procedures. The subjects were divided into three groups according to the record utilized for the analysis. The putters of the group A (average record: 20.13 m) tended to be taller and heavier compared to those of the group B (18.01 m) and C (16.13 m). Initial velocity of the shot correlated significantly with the putting distance, and had the greatest influence on the record among the release parameters. There was no statistical significant difference in velocity of body center of gravity among the groups neither in glide phase nor at release instant. The shot was accelerated abruptly in thrust phase. The peak force and power exerted on the shot correlated strongly with the putting distance. At the release instant, there was no significant difference among the groups in any kinematic variables obtained. At the end of the glide phase, support leg knee was more flexed and shoulder was more twisted against the putting direction in group A compared to other two groups. The most important concept for successful performances in shot putting would be that the athletes should take up a good body position suitable for a powerful thrusting phase which will allow for the highest possible velocity of release.

INTRODUCTION

The world record of male shot put event as of November 30, 1998 is 23.12 m. This record was established by Randy Barnes from USA and has been existing for more than eight years. In 1987 there were more than 50 athletes marked 20.00 m or longer, while only 25 putters could in 1997. The competing level in the event has been stagnant for these years.

In recent competitions, two techniques are mainly used by the putters, one is glide technique and another is rotational technique. Glide technique is also called as "O'Brien Style" after the inventor of the technique. In 1997 World Championship in Athens, four of eight top prize athletes put with the glide technique in male event, and all of eight in female event. Though the rotation technique has been popular, glide technique is still the most dominant in both male and female shot put competitions.

There have been rather more biomechanical research works done on the comparatively new rotational technique (3, 9, 10), while the traditional glide technique has been left with very few detailed investigation.

The purpose of this study was to compare the shot put motion among male athletes using glide technique with various competing levels. Three dimensional image analysis was used for this purpose. Knowledge of correct putting mechanics in shot put event would assist an athlete in developing proper skill and competing level.

METHODS

DATA COLLECTION

The putting motions of male competitors were recorded using three-dimensional (3-D) motion analysis procedures during finals of three international athletic competitions. They were (a) 3rd IAAF World Championship in Athletics

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Tokyo '91, (b) '93 TOTO International Super Track and Field Meet in Fukuoka, and (c) The 12th Asian Games in Hiroshima '94.

In the first two competitions (a, b) a set of two high-speed movie cameras (Photo-Sonics 1PL) were used. In the last competition (c) a set of two high-speed video cameras (NAC HSV-400) were used. In all the cases, the two cameras were placed in the audience stand, and the shatter operation of two cameras were phase-locked electrically. The angle between the optical axes of two cameras was approximately 60 - 90 degrees. The nominal recording frequency was (a) 100 frames/s, (b) 50 frames/s, and (c) 200 fields/s, respectively.

A vertical pole containing two markers with heights of 0.250 m and 2.500 m were used to permit calibration of the space. At nine places encompassing the space of movement of the putting action, the pole was set vertically and recorded with the same camera set-up as the filming or video-recording of the putting motion.

SUBJECTS

The motion of 24 right-handed male shot putters using glide technique was chosen for the analysis. The best trial at the competition for each subject were selected for the analysis.

The subjects were divided into three groups according to the record utilized for the analysis (Table 1). Record of the analyzed trial for group A was 21.67 - 19.24 m (n = 9, average: 20.13 m), 18.91 - 17.12 m for group B (n = 7, 18.01 m), and 16.77 - 15.81 m for group C (n = 8, 16.13 m). The records of analyzed trial corresponded to 81.8% to 102.2% of the previous personal best, and the average rate was 96.8%, 94.9%, and 95.6% for group A, B, and C, respectively (n.s.).

Physical characteristics of the subjects of each group were also shown in Table 1. The putters of the group A tended to be taller and heavier compared to those of the group B and C (height: $p < 0.001$, body mass: n.s.).

DATA ANALYSIS

There are several approaches to subdividing shot put performance (12). It seems that there is a general agreement among researchers (2, 4, 6, 8) that the putting sequence is divided by four important temporal events corresponding to the time of rear foot off (R-off), rear foot on (R-on), front foot on (F-on), and shot release (S-rls). The putting motion is divided into five phases with these four events, as shown in Figure 1. The frame immediately after shot release was assigned the time t = 0.00 s, and digitizing was performed over a range from 0.30 s before the initial R-off till 0.10 s after the S-rls.

Landmarks on the body and the center of the shot were digitized in each image. For the film, a projection head (NAC Inc., 160B) was used to cast the film images onto the surface of a digitizer (Graphtech Inc., G-5050). For the video, image was projected onto a personal computer (Sharp Co. Inc., X-68000). Digitizing was executed every frame for the first two competitions and every other field (100

Table 1: Characteristics of the subjects

Group	Record (m)	n	Age (yrs)	Height (m)	Body Mass (kg)	PB (m)	Trial (m)	%PB
A	19.24-21.67	9	26.8 (3.1)	1.928 (0.056)	120.8 (9.0)	20.81 (1.04)	20.13 (0.82)	0.968 (0.029)
B	17.12-18.91	7	26.3 (4.6)	1.857 (0.038)	117.0 (9.9)	19.08 (1.96)	18.01 (0.77)	0.949 (0.065)
C	15.81-16.77	8	27.3 (3.8)	1.849 (0.053)	110.4 (9.0)	16.89 (0.73)	16.13 (0.40)	0.956 (0.039)
			n.s.	*** A>B,C	n.s.	*** A>B>C	*** A>B>C	n.s.
All		24	26.7 (3.5)	1.882 (0.061)	116.5 (9.9)	19.00 (2.09)	18.18 (1.84)	0.958 (0.044)

Note. Values are average and (SD)
PB : personal best, Trial : record of the analyzed trial, %PB=Trial/PB
* shows the statistical differences among three groups (*** : p<0.001)

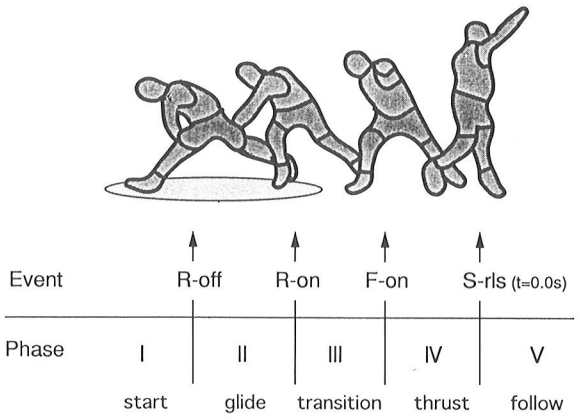

Figure 1: Important temporal events and phases in glide technique of shotput. R-off: Rear Foot Off, R-on: Rear Foot On, F-on: Front Foot On, S-rls: Shot Release

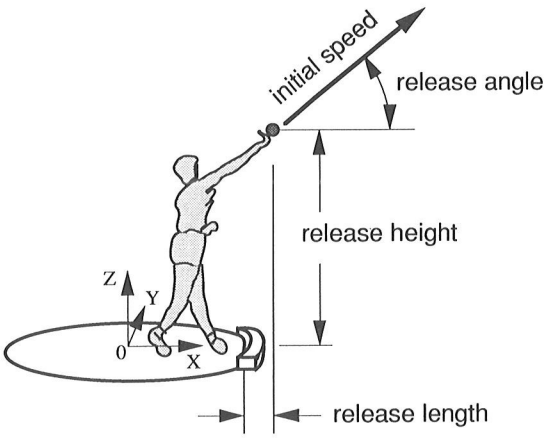

Figure 2: Definition of the initial parameters of shot release

Hz) for the last competition.

The right-handed orthogonal reference frame was defined by axes X, Y, and Z with the origin at the center of the putting circle. The Z axis was defined as vertical, the X axis was defined as horizontal and pointing toward putting direction, and the Y axis was then defined as the cross product of the Z and X axes.

The DLT procedures (1) were used for 3-D space reconstruction from the 2-D images of the putting motion. The time-dependent 3-D coordinates of each landmark were smoothed with a fourth order zero-lag digital filter of the Butterwoth type with a resultant cut-off frequency of 5.0 Hz (11). All subsequent calculations were performed with these smoothed landmark data.

Velocity vector and position of the shot at release instant decide the distance covered by the trial. The definition of these initial release parameters are shown in Figure 2.

Changes of knee and elbow angle on right side of the body in 3-D space were obtained. Shoulder and hip direction in horizontal plane was also calculated and assigned 90 degrees when trunk facing toward the putting direction.

Body center of gravity (CG) was calculated using anthropometric parameters reported by Matsui (7). Velocity and acceleration changes of CG and shot was obtained. Force exerted on the shot was calculated as a product of mass and acceleration of the shot. Power exerted on the shot was obtained as a scalar product of the force and velocity of the shot.

An analysis of variance (ANOVA) was used to examine the statistical significance among the variables for the three groups. The Fisher's PLSD post hoc analysis provided a measure of the significance between each possible pair of groups. A probability of $p < 0.05$ was required for significance.

RESULTS

The results of the temporal analysis of foot placement are shown in Table 2. No significant difference was observed in the foot contact timing patterns among the groups. There was no significant difference observed in the duration of any phases including glide phase among the groups.

Release parameters such as initial velocity, angle of release, release height and length were obtained and the mean and average values for each group were shown in Table 3. Initial velocity of the shot (group A: 13.43 ± 0.33 m/s, B: 12.40 ± 0.32 m/s, and C: 11.80 ± 0.22 m/s) correlated strongly with the putting distance, and had the greatest influence on the record among the release parameters. Though release angle had less influence on the putting distance, the world top athletes (group A) put the shot higher (38.8 ± 1.8 deg) compared to those of group C (35.2 ± 2.9 deg, $p < 0.05$). Release height and length has no relationships with the putting distance when they are normalized by the subjects' height.

Figure 3 shows the changes of shoulder and hip rotation

Table 2: Time of selected temporal events (second)

		phase :	start	glide	transition	thrust	follow
Group	n	event :	R-off		R-on	F-on	S-rls
A	9		-0.517 (0.040)		-0.364 (0.029)	-0.275 (0.027)	0.000
B	7		-0.501 (0.048)		-0.352 (0.043)	-0.255 (0.027)	0.000
C	8		-0.523 (0.025)		-0.373 (0.023)	-0.256 (0.016)	0.000
			n.s.		n.s.	n.s.	
All	24		-0.515 (0.038)		-0.364 (0.032)	-0.263 (0.025)	0.000

Note. R-off : support (rear) foot off, R-on : support foot on, F-on : stride (front) foot on, S-rls : shot release
Values are average and (SD), when the frame of shot release (S-rls) was assigned the time t=0s.

Table 3: Summary of the release parameters

Group	n	Initial Speed (m/s)	Release Angle (deg)	Release Height (m)	Release Length (m)	RH/H ratio	RL/H ratio
A	9	13.43 (0.33)	38.8 (1.8)	2.267 (0.044)	0.071 (0.074)	1.179 (0.037)	0.037 (0.038)
B	7	12.40 (0.32)	37.6 (2.9)	2.139 (0.073)	0.095 (0.049)	1.159 (0.032)	0.052 (0.027)
C	8	11.80 (0.22)	35.2 (2.9)	2.160 (0.116)	0.106 (0.110)	1.169 (0.061)	0.068 (0.053)
		*** A>B>C	* A>C	* A>B,C	n.s.	n.s.	n.s.
All	24	12.56 (0.78)	37.1 (2.9)	2.196 (0.099)	0.090 (0.083)	1.170 (0.044)	0.051 (0.042)

Note. Values are average and (SD)
RH/H ratio and RL/H ratio : Release Height and Release Length when normalized by the subject height, respectively
RH/H ratio = Release Height / Subject Height, RL/H ratio = Release Length / Subject Height
* shows the statistical differences among three groups (* : $p<0.05$, *** : $p<0.001$)

angle in horizontal plane for the trial of Gunthor from Switzerland, who was a Gold medalist in World Championship '91 and marked the highest record among the trials for the analysis. Figure 4, 5, and 6 shows the changes in 3-D joint angle of right elbow and right knee (Figure 4), velocity changes of the shot and the CG of the putter (Figure 5), and the force and power exerted to the shot (Figure 6), respectively in the same trial as in Figure 3. The general tendencies of the changes of these variables were very similar for all the subjects.

Table 4 shows the comparison of several angles shown in Figures 3 and Figure 4 at the instants of R-on and S-rls among three subject groups. At the S-rls instant, there was no significant difference among the groups in any angles. At the R-on instant, knee was more flexed in group A compared to other two groups. Significant difference between group A and group C was also observed in shoulder horizontal angle at the R-on instant. Shoulder tended to be much twisted against the putting direction in the group of better performance. In group A, shoulder was facing almost backward at the end of the glide phase.

As for the velocity of CG in the putting direction in

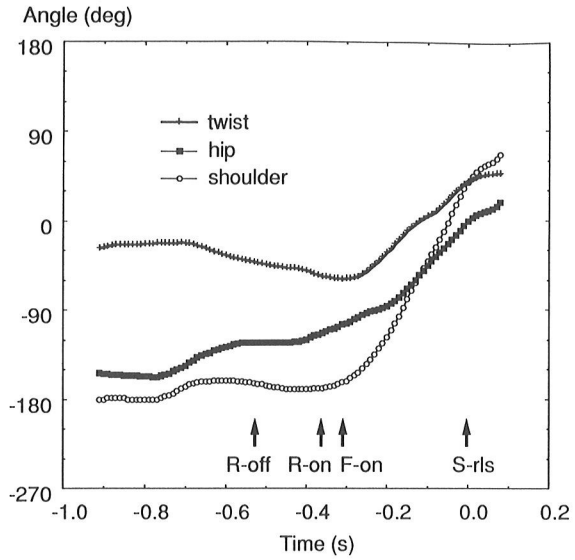

Figure 3: Changes of shoulder and hip rotation angle in horizontal plane for the trial of Gunthor (21.67 m). The difference between two angles is also shown as "twist" angle. Important temporal events are indicated as defined in Figure 1.

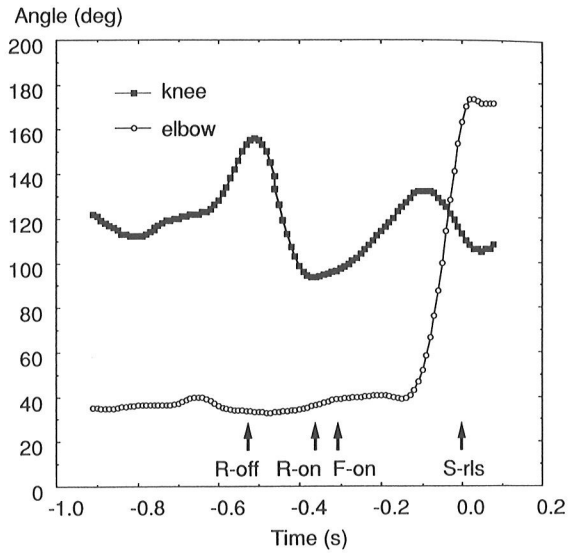

Figure 4: Changes of right knee and right elbow joint angle in 3-D space for the same trial in Figure 3.

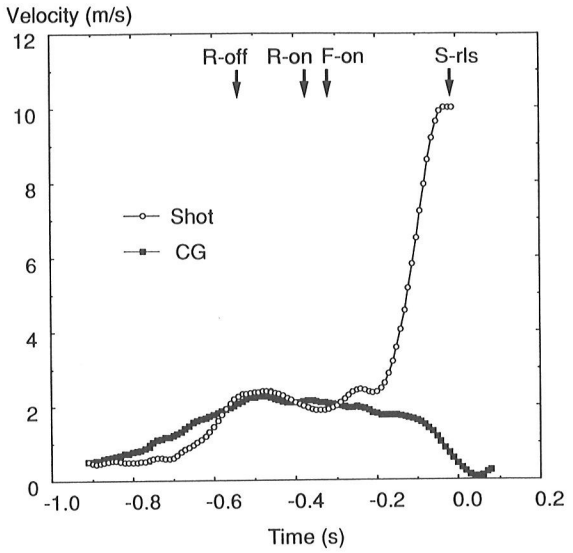

Figure 5: Changes of velocity of shot and body center of gravity (CG) in X direction for the same trial in Figure 3.

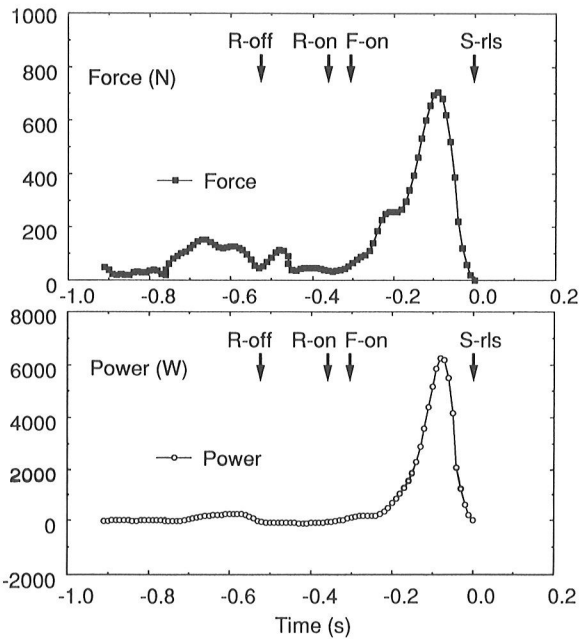

Figure 6: Changes of force (upper) and power (lower) exerted on the shot for the same trial in Figure 3.

Table 4: Segment and joint angle kinematics at the selected temporal events.

	temporal event	R-on					S-rls				
	Angle (deg)	Knee	Elbow	Shoulder	Hip	Twist	Knee	Elbow	Shoulder	Hip	Twist
Group	n										
A	9	99.2	39.4	-178.7	-124.1	-54.4	136.8	158.0	22.1	0.4	21.7
		(3.9)	(7.7)	(13.5)	(15.7)	(14.4)	(19.9)	(10.8)	(10.8)	(13.6)	(17.2)
B	7	105.1	36.1	-167.1	-120.7	-46.5	143.4	148.1	24.1	6.3	17.8
		(3.4)	(11.6)	(15.5)	(21.3)	(23.4)	(13.9)	(3.5)	(10.8)	(10.4)	(10.3)
C	8	106.1	32.4	-164.5	-117.7	-46.6	141.0	149.5	16.5	-3.4	19.9
		(6.9)	(7.6)	(7.0)	(17.0)	(11.4)	(10.1)	(8.2)	(6.0)	(6.1)	(3.2)
		*	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		A<B,C		A<C							
All	24	103.2	36.1	-171.0	-121.0	-49.5	140.1	152.2	20.8	0.9	20.0
		(5.7)	(9.1)	(14.0)	(17.0)	(16.4)	(15.1)	(9.2)	(9.6)	(10.9)	(11.7)

Note. Values are average and (SD)
R-on : time of rear foot on = end of glide phase,. S-rls : time of shot release from the hand
* shows the statistical differences among three groups (* : $p<0.05$)

Table 5: Comparison of CG velocity and several kinetic parameters among three groups.

		CG vel		E-shot		F-max	P-max
		R-on	S-rls	R-on	S-rls		
Group	n						
A	9	2.27	0.56	98	813	638	5552
		(.22)	(.17)	(9)	(31)	(54)	(435)
B	7	2.39	0.68	100	728	560	5004
		(.17)	(.31)	(8)	(39)	(53)	(470)
C	8	2.34	0.66	99	659	501	4246
		(.18)	(.29)	(1)	(17)	(56)	(299)
		n.s.	n.s.	n.s.	***	***	***
					A>B>C	A>B>C	A>B>C
All	24	2.33	0.63	98	737	569	4957
		(.19)	(.25)	(7)	(72)	(79)	(683)

Note. Values are average and (SD)
CG vel : velocity of the body center of gravity in x direction
E-shot : mechanical energy of the shot
F-max and P-max : maximum value of force and power exerted on the shot during the putting movement, respectively
R-on : time of rear foot on = end of glide phase, S-rls : time of shot release from the hand
* shows the statistical differences among three groups (*** : $p<0.001$)

glide phase and at S-rls instant, average and standard deviation values for each group was obtained and shown in Table 5. Mechanical energy of the shot at R-on and S-rls instants and peak values of force and power exerted on the shot during the thrust phase were obtained and were also shown for three groups in Table 5. There was no statistical significant difference in CG velocity among the groups neither in glide phase nor at S-rls instant. Mechanical energy of the shot at R-on instant did not differ as well among three groups. The shot was accelerated abruptly in thrust phase. The peak force and power exerted on the shot was obviously larger in subjects with better performance.

DISCUSSION

Average height and body mass of all the subjects was 1.882 m and 116.5 kg, respectively. Though the subjects with higher competing level tended to be taller and heavier, there were several putters in group A whose physique were shorter and lighter than these average values. Therefore the size of the athletes is not necessarily a prerequisite for the world elite shot-putters.

Temporal patterns of foot placement did not vary among the three groups. Therefore the glide techniques employed by the putters in three groups did not differ essentially. Dessureault (4) reported that the best performers tended to reduce their times of execution during the last three phases, specifically during the thrusting phase. One of the reasons for the discrepancies of the results between two studies would be that the competing level of the previous study was extremely wide (20.68 m - 10.66 m).

McCoy (8) investigated four to fourteen trials of America's top putters and found a correlation of $r = -0.49$ between the angle of release and distance thrown. This fact indicated that as the angle of release decreased the distance of the throw increased for a certain subject. In this study, the athletes of group A put the shot higher compared to those of group C. The world top level athletes have the ability to do larger work on the shot with higher release angle.

When teaching the glide technique, one of the most important points has been thought as the acceleration of body center of gravity during the start phase. Some coaches and researchers thought the larger the CG speed in glide phase is the larger the shot speed can be gotten. Ariel (2) reported that CG velocity in glide phase was clearly higher for world top athletes compared to national level athletes. Contrary to his finding, in the present study, the velocity of CG showed no significant differences among the groups in any temporal events including the end of the glide phase.

During the following transition and thrust phases, the shot was accelerated vigorously. The force and power exerted on the shot during these phases were remarkably larger for the groups with higher performance. Consequently, the velocity of the shot at the release instant resulted in being larger for these groups. Marhold (6) mentioned that technically perfect athletes were superior to others to increase the velocity of the shot prior to the beginning of the thrust phase. Francis (5) thought that the shot velocity increased continuously throughout the throw. The results obtained in this study did not support their ideas.

Within a limit of the kinematic variables investigated in this study, there were significant differences among three groups only for knee joint angle and shoulder directional angle at the R-on instant. Tendency that knee was more flexed and shoulder was more twisted against the putting direction for group A at the end of the glide phase was observed.

Knee joint was extended in start phase and then flexed drastically in the consequent glide phase. In this time sequence, flexed position of the knee joint would be more advantageous for the mighty force and power exertion during the following transition and thrust phases.

Ariel (2) revealed that CG was maintained at approximately the same height for Olympic throwers throughout the glide, transition, and into the beginning of the thrust phase. While, national level athletes elevated the CG continuously during all phases of the throw. Lowered position of the CG would be competent for force and power exertion in the following time period and the results obtained in this study seems consistent with his finding.

In the same way twisted position of the trunk against the putting direction prior to the acceleration phases would be more advantageous as well for the putter to bring the power exertion ability into full play.

These results suggested that putters should maintain a posture in the glide phase favorable to increase the force and power exertion during the latter phases for better performance. The most important concept for successful performances in shot putting would be that the athletes should take up a good body position suitable for a powerful thrusting phase which will allow for the highest possible velocity of release.

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