A PRELIMINARY STUDY OF ROTATIONAL SHOT PUT TECHNIQUE

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INTRODUCTION: The rotational throwing events in track and field, the shot put, discus and hammer throw are technically very demanding. They involve complex movements performed at high speed in a limited space. The throwing distance in the shot put is determined by release velocity, angle of release, height of release and overreaching or incomplete reaching of the shot (Stepanek 1990). A taller thrower with longer arms has an advantage over a shorter thrower in the height and overreaching of release. The angle of release is determined by a combination of horizontal and vertical forces developed from the circle through rotation and extension movements of the kinematic chain of the body where the legs, the trunk and the dominating arm are involved. The release velocity depends on the impulse through a change in momentum in the shot. Both force and time influence the impulse, and therefore also the velocity. The human link system in the shot put acts rhythmically in the rotational and linear movement sequences of the total performance. The primary power is generated from the ground in the form of ground reaction forces as a result of leg action. The link system works from the proximal body segments (legs) to the distal segment (hand). The athlete who has the highest release velocity and release height, optimal release angle (42.3 deg., Lichtenberg and Wills, 1976) and maximal overreaching will throw the shot the farthest.
The purpose of this study was to identify those characteristics of the rotational shot put technique of an elite male shot putter that are related to his record distances (three top throws) during two consecutive seasons.

METHODS: The subject of this preliminary study was a right handed elite shot putter (AH) in the men's shot put event in the main competitions of 1996 and 1997 in Finland.
Two JVC VHS (PAL) and two Magnafox VHS (NTSC) video cameras, operating at a sampling frequency of 50 (PAL) and 60 Hz (NTSC), were used to record the performances. One camera was placed to the rear of the throwing circle and the other one was placed to the side, in line with the midline of the circle. The angle between the optical axis of the two cameras was approximately 90 deg. The three best trials according to the official distance were selected for analysis.
A 2.03 m x 2.54 m x 2.03 m rectangular parallelepiped reference scaling frame was placed in the throwing circle before and after each competition and its position was recorded for calibration purposes.
Each trial was digitized with an Ariel Performance Analysis System (APAS), starting five fields before the backward limit of the final preliminary swing was reached and ending with the last field in which the shot was still in the field of view. The DLT procedure was used to obtain 3D coordinate data for 18 body landmarks and the center of the shot. This raw data was then smoothed using a Cubic spline algorithm.

The horizontal (v_H), vertical (v_V) and resultant (v_R) velocities, angle of release (α_R) and height of release (h_R) were obtained using the APAS analysis system.
The phases of the shot put were as follows: the first double support phase is from the end of the final preliminary (t_1) swing to the instant the athlete's right foot breaks contact with the ground (t_2); the first single support phase is from the end of the first double support phase (t_2) to the instant the thrower's left foot breaks contact with the ground (t_3); the flight phase is from the end of the first single support phase (t_3) to the instant the athlete's right foot regains contact with the ground (t_4); the second single support phase is from the end of the flight phase (t_4) to the instant the athlete's left foot regains contact with the ground (t_5); and the second double support phase is from the end of the second single support phase (t_5) to the instant of release of the shot (t_6). This last phase involves a period of double support.
Assuming that the speed of the shot at the end of the final preliminary backswing is zero, its speed (v_R) at the instant of release can be expressed as:

$$v_R = dv_{1D} + dv_{1S} + dv_A + dv_{2S} + dv_{2D} \qquad (1)$$

where dv_{1D} , dv_{1S} , dv_A , dv_{2S} and dv_{2D} are, respectively, the changes in the speed of the shot during the first double support phase, the first single support phase, the flight phase, the second single support phase, and the second double support phase.
The subject's samples (1996 and 1997) were considered separately. Means and standard deviations were computed for each variable and the statistical significance of means was tested with Student's t-test.

RESULTS: The means, standard deviations, and individual values of the official distances, as well as the speed, angle and height of release of the shot are shown in Table 1.

Table 1. The official distances (d), resultant (v_R) velocities, angle of release (α_R) and height of release (h_R) of the analyzed shots of AH.

Subject	**d (m)**	**v_R (m/s)**	**α_R (deg)**	**h_R (m)**
AH96_1	18,65	12,39	38,80	2,14
AH96_2	19,06	12,71	35,51	2,11
AH96_3	18,75	12,30	40,48	2,11
Average	18,82	12,47	38,26	2,12
S.D.	0,21	0,22	2,53	0,02
AH97_1	20,06	13,21	37,36	2,10
AH97_2	20,66	13,32	39,44	2,15
AH97_3	20,05	13,04	36,42	2,09
Average	20,26	13,19	37,74	2,11
S.D.	0,35	0,14	1,55	0,03

The distance of the top three shot puts increased significantly from 1996 to 1997 ($t=-6.08$, $df=4$, $p=.004$), as did the release speed ($t=-4.86$, $df=4$, $p=.008$). The duration of the different phases was shorter in the first double support ($t=36.42$, $df=4$, $p=.000$) and flight ($t=10.39$, $df=4$, $p=.000$) phases and also in the total ($t=21.80$, $df=4$, $p=.000$) performance (Table 2). The shorter duration of these phases demonstrated a better performance and a longer distance of the shot. The path of the shot before the release was 3.76 $\pm$ 0.12 m in 1996 and 3.29 $\pm$ 0.03 m in 1997 ($t=6.63$, $df=4$, $p=.003$).

Table 2. The duration of the first double support phase (t_2-t_1), the first single support phase (t_3-t_2), the flight phase (t_4-t_3), the second single support phase (t_5-t_4), the second double support phase (t_6-t_5) and the total duration (t_6-t_1) of AH.

Subject	**d (m)**	**t_2-t_1 (s)**	**t_3-t_2 (s)**	**t_4-t_3 (s)**	**t_5-t_4 (s)**	**t_6-t_5 (s)**	**t_6-t_1 (s)**
AH96_1	18,65	0,70	0,40	0,14	0,20	0,18	1,62
AH96_2	19,06	0,68	0,40	0,14	0,18	0,20	1,60
AH96_3	18,75	0,68	0,44	0,14	0,18	0,20	1,64
Average	18,82	0,69	0,42	0,14	0,19	0,19	1,62
S.D.	0,21	0,01	0,02	0,00	0,01	0,01	0,02
AH97_1	20,06	0,33	0,46	0,08	0,18	0,19	1,24
AH97_2	20,66	0,35	0,43	0,09	0,21	0,20	1,28
AH97_3	20,05	0,35	0,42	0,07	0,21	0,20	1,25
Average	20,26	0,34	0,44	0,08	0,20	0,20	1,26
S.D.	0,35	0,01	0,02	0,01	0,02	0,01	0,02

Mean values for the speed of the shot at the end of the five phases, and for the changes in speed during each phase, are presented in Table 3. The speed of the shot decreased significantly at the end of the first double support phase ($t=3.04$, $df=4$, $p=.038$) and the second single support phase ($t=3.93$, $df=4$, $p=.017$). The speed at the end of the second double support phase is equal to the release speed.

Table 3. Speed of the shot at the end of the first double support phase (v_{1D}), the first single support phase (v_{1S}), the flight phase (v_A), the second single support phase (v_{2S}) and the second double support phase (v_{2D}) of AH.

Subject	**d (m)**	**v_{1D} (m/s)**	**v_{1S} (m/s)**	**v_A (m/s)**	**v_{2S} (m/s)**	**v_{2D} (m/s)**
AH96_1	18,65	2,49	2,44	1,46	2,95	12,39
AH96_2	19,06	2,93	2,49	0,74	2,82	12,71
AH96_3	18,75	2,82	2,51	0,87	2,87	12,30
Average	18,82	2,75	2,48	1,02	2,88	12,47
S.D.	0,21	0,23	0,04	0,38	0,07	0,22
AH97_1	20,06	2,39	1,32	1,02	2,65	13,21
AH97_2	20,66	2,24	2,35	1,01	2,35	13,32
AH97_3	20,05	2,34	2,24	1,07	2,32	13,04
Average	20,26	2,32	1,97	1,04	2,44	13,19
S.D.	0,35	0,08	0,57	0,03	0,18	0,14

The changes in the speed of the shot in 1996 and 1997 during the first double support phase (dv_{1D}) were 2.75 $\pm$ 0.23 m/s and 2.34 $\pm$ 0.08 m/s ($t=3.04$, $df=4$, $p=.038$), during the first single support phase (dv_{1S}) -0.27 $\pm$ 0.20 m/s and -0.35 $\pm$ 0.63 m/s (n.s:), during the flight phase (dv_A) -1.45 $\pm$ 0.43 m/s and -0.93 $\pm$ 0.56 m/s (n.s.), during the second single support phase (dv_{2S}) 1.85 ± 0.33 m/s and 1.41 ± 0.19 m/s (n.s.), and during the second double support phase (dv_{2D}) 9.59 ± 0.26 and 10.75 ± 0.21 m/s (t=-6.03, df=4, p=.004), respectively.

DISCUSSION: The average official distances of the top three throws of AH were 18.82 ± 0.21 m in 1996 and 20.26 ± 0.49 m in 1997 with a lowered angle of release. However, this means progress in the throwing technique. The data revealed changes in the timing and speed profiles of the athlete's throws. In the timing profile, the first double ground support phase, the flight phase and the total performance time decreased significantly. In the speed profile, the speed of the first double support phase and the second single support phase decreased significantly as well. A small loss in speed was observed during the flight phase. A small gain in speed was obtained during the second single support phase and a dramatic gain in speed during the final throwing action.
The speeds, angles and heights of release were generally similar to those reported by previous investigators for shot put performances of comparable distance (Stepanek 1989 & 1990 and Palm 1990) and with three-dimensional methodology taking into account a relatively low frame frequency in video shooting of this study.
The early phase of the shot's path from the end of the back turn of the upper body to the planting of the right foot in the middle of the circle tends to pre-accelerate the entire system (thrower-shot) producing optimal velocity and momentum. During the beginning of the turn when the body weight shifts from the right over the left leg the velocity of the shot increased up to 2-3 m/s. This is in agreement with Stepanek 1989. After the push-off from the right leg and the weight transfer over to the left leg, the velocity tends to decrease. This occurs during the turn around the left ball and the push-off from the left foot into the turn. The velocity also tends to decrease during the flight phase. This may be mainly due to the tendency to minimize the radius of rotation of the shot and to decrease the moment of inertia of the "thrower-shot" system. However, this maneuver may increase the angular velocity of the body around the vertical axis of the thrower. The main delivery starts during the planting of the right foot in the middle of the circle and ends with the release of the shot. The main goal is to transform maximum energy and velocity to the shot with optimal direction of movement inside the circle.

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