（財）日本陸上競技連盟
陸上競技研究紀要
第５巻, 132-142, 2009

Bulletin of Studies
in Athletics of JAAF
Vol.5,132-142,2009

A biomechanical analysis of the men's shot put at the 2007 World Championships in Athletics

Keigo Ohyama Byun[1)], Hiroaki Fujii[1)], Masatoshi Murakami[2)],
Toshinori Endo[3)], Hisashi Takesako[4)], Koki Gomi[4)] and Kenji Tauchi[4)]
1) Graduate School of Comprehensive Human Sciences, University of Tsukuba,
2) Ehime Women's College, 3) Aoyama Gakuin University, 4)Waseda University

Abstract

The aims of this study are to present a biomechanical overview of the performances of the finalists the men's shot put at the 2007 IAAF World Championships in Athletics and make comparisons of the techniques of the three medalists. Video recordings of the best throw by each of the top ten placed athletes were analyzed. The authors looked at the technical differences between the glide and rotation techniques and between variations of the rotation. They focused on the acceleration profile, with reference to both the shot itself and the athlete's body. They also analyzed the sequence from athlete-shot system acceleration through to the final acceleration of shot in the delivery. The results suggest that shot velocity alone is not enough to explain the process of acceleration as whole-body momentum is gained or maintained even as there is a marked decrease of shot velocity during flight and transition phases of the rotation technique.

Introduction

Unlike the high jump, where the Fosbury Flop is practically the only technique used at any level of competition, the shot put is characterised by the coexistence of two mainstream techniques – the glide and the rotation. The top ten placers at the 2007 World Championships in Athletics in Osaka confirmed this situation; six used the rotation while the other four used the glide and both techniques were found in the three medallists.

The fact that the two techniques lead to a common delivery from totally different preparations is a matter of great interest among both coaches and athletes. Some previous findings have shown that the advantage of rotational technique is in the long acceleration path of the shot[1),2),3)]. But the experimental evidence is not conclusive. The unfavourable drop in the velocity of the shot during the flight and transition phases has been frequently reported as a disadvantage[4),5)]. However, it has been shown that, in spite of this deceleration, the athlete's body does move forward and it can be favourable for delivery[2),6)]. In terms of the potential momentum within the athlete-shot system, the apparent loss of the shot's velocity is not necessarily a critical issue. Writing about the discus throw, Schluter & Nixdorf reported that the amount of discus acceleration during the transition phase, the last half of preparation, is negatively correlated to the discus velocity at release[7)]. In other words, the temporarily inappropriate state of the implement is not a problem, provided the system is ready to ensure the final delivery by transferring the momentum to the implement. The aims of this study are to present a biomechanical overview of the performances of the finalists the men's shot put in Osaka and to make comparisons of the techniques of the top three putters. We will look at the technical differences between the glide and rotation techniques and between variations of the rotation. Our focus will be on the acceleration profile, with reference to both the shot itself and the athlete's body, and we will analyse the sequence from athlete-shot system acceleration to the final acceleration of shot in the delivery.

Table 1: Official results and release parameters for men's shot put at the 2007 World Championships in Athletics

Rank	Name	Country	Result (m)	Technique	Release Parameters		
					Velocity (m/sec)	Angle (º)	Height (m)
1	Reese HOFFA	USA	22.04	Rotation	14.07	32.35	2.34
2	Adam NELSON	USA	21.61	Rotation	14.06	30.77	2.38
3	Andrei MIKHNEVICH	BLR	21.27	Glide	13.44	37.48	2.56
4	Rutger SMITH	NED	21.13	Rotation	13.34	37.66	2.35
5	Tomasz MAJEWSKI	POL	20.87	Glide	12.99	37.55	2.58
6	Mirian VODOVNIK	SLO	20.67	Rotation	13.42	33.63	2.26
7	Ralf BARTELS	GER	20.45	Glide	13.31	35.10	2.11
8	Yuriy BIALOU	BLR	20.34	Rotation	13.24	36.70	2.22
9	Dylan ARMSTRONG	CAN	20.23	Rotation	13.18	34.29	2.10
10	Pavel SOFIN	RUS	19.62	Glide	12.83	35.31	2.39

Methods

Data were collected during the men's shot put final at the 2007 IAAF World Championships in Athletics on 25 August. The best attempt from each of the top ten placed putters was analysed (the other two finalists did not record valid marks). All of the athletes studied were right handed.

Two digital video cameras (HVR-A1J, SONY) were used to record the putters' motion at 60fps and exposure time was set at 1/1000sec. One camera was fixed at the back and the other at the right side of the throwing circle. The shot of all ten putters and end points of each body segment of the top three putters were manually digitized in every frame with a motion analysis system (Frame-Dias; DKH Inc.) from video images. A 14-segment model comprising hands, forearms, upper arms, foot, shanks, thighs, head, and trunk was constructed. Three-dimensional coordinates of 24 points were obtained using a Direct Linear Transformation (DLT) technique[8)], and smoothed by a fourth- order Butterworth low-pass digital filter cutting off at 2.4 to 7.8Hz, determined by residual analyses[9)]. Standard errors in the constructed coordinates of the control points were 0.006m (x- axis), 0.004m (y-axis), and 0.007m (z-axis).

The locations of the centre of mass and the moment of inertia for each body segment of were estimated from the body segment inertia parameters developed by Ae et al[10)].

For analysis and description of the data, the putting motion was divided into several phases (Figure 1). The phases of preparation, flight, transition and delivery were assigned with respect to the information on foot contact. To analyse the motion, a global reference frame was set. The Y-axis was aligned to the putting direction (pointing at front). The Z-axis was the vertical direction (pointing at the top), and the X-axis was perpendicular to the Y- and Z- axes (pointing at the right). In particular, the trunk twist and tilt angle were calculated on the local reference frame fixed on the pelvis. These parameters indicate relative precedence of pelvis rotation to the shoulder axis rotation about longitudinal axis of the trunk and the tilting angle of trunk within the sagittal plane respectively.

Results

Table 1 shows the official results of the competition. It also shows the condition of the shot at the moment of release for the athlete's best put. The official result correlates significantly with the velocity at release ($r=0.87$, $p<0.01$).

The shot trajectories on the X-Y plane and the Y-Z plane for all ten putters are showed in Figure 1. In the X-Y plane, the four gliders show an almost linear trajectory. The shots of rotators follow a circle-shaped path in the first half of turn. However a "loop" portion of trajectory during the flight and transition phases is seen only in Smith.

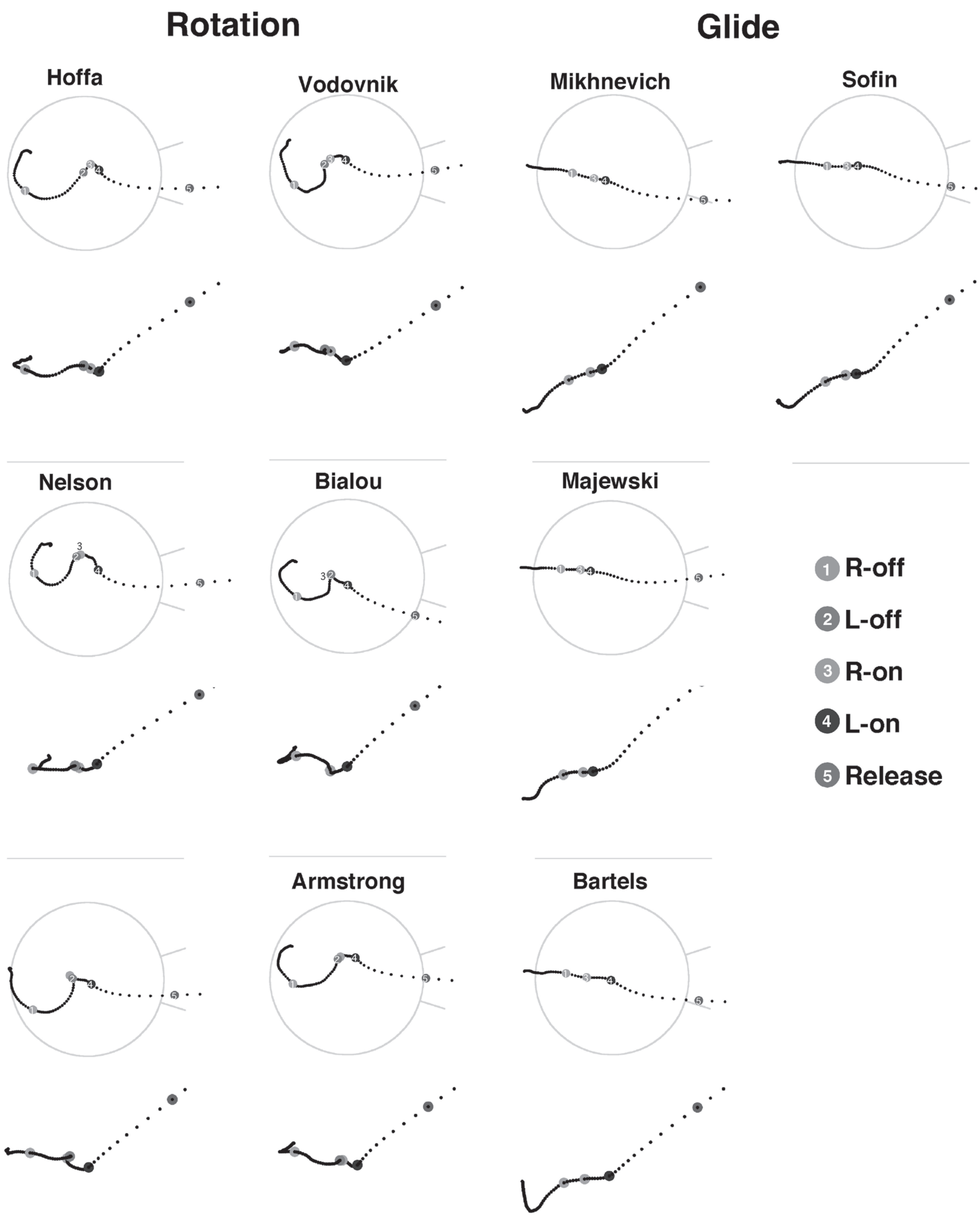

Figure 1. Shot trajectory on X-Y plane (top view) and Y-Z plane (side view) of ten puttersFigure putters

The time courses of the shot velocity for all ten putters are represented on Figure 2. Regardless of preparation style, most of the acceleration takes place in the delivery phase. While the rotational putters show two or more peaks before the flight phase, the glide putters show a single peak corresponding to the push off of the right leg and the swing of the left leg. In both techniques, a decrease in velocity can be seen during the flight and transition phases, with the fall greater in the rotation than the glide.

Figure 3 shows the duration of each phase from the flight to release. The flight phase is longer in the glider putters than the rotation putters. Among the rotators, Bialou shows no flight phase. While the transition phase is extremely long in rotators, the delivery is longer in the gliders. The only rotator whose delivery is as long as the gliders is Hoffa.

More detailed analyses were conducted on the throws of the three medallists. Figures 4a, 4b, 4c show the time courses of the shot velocity, the linear momentum and the angular momentum about the centre of mass (CM) for the three medallists.

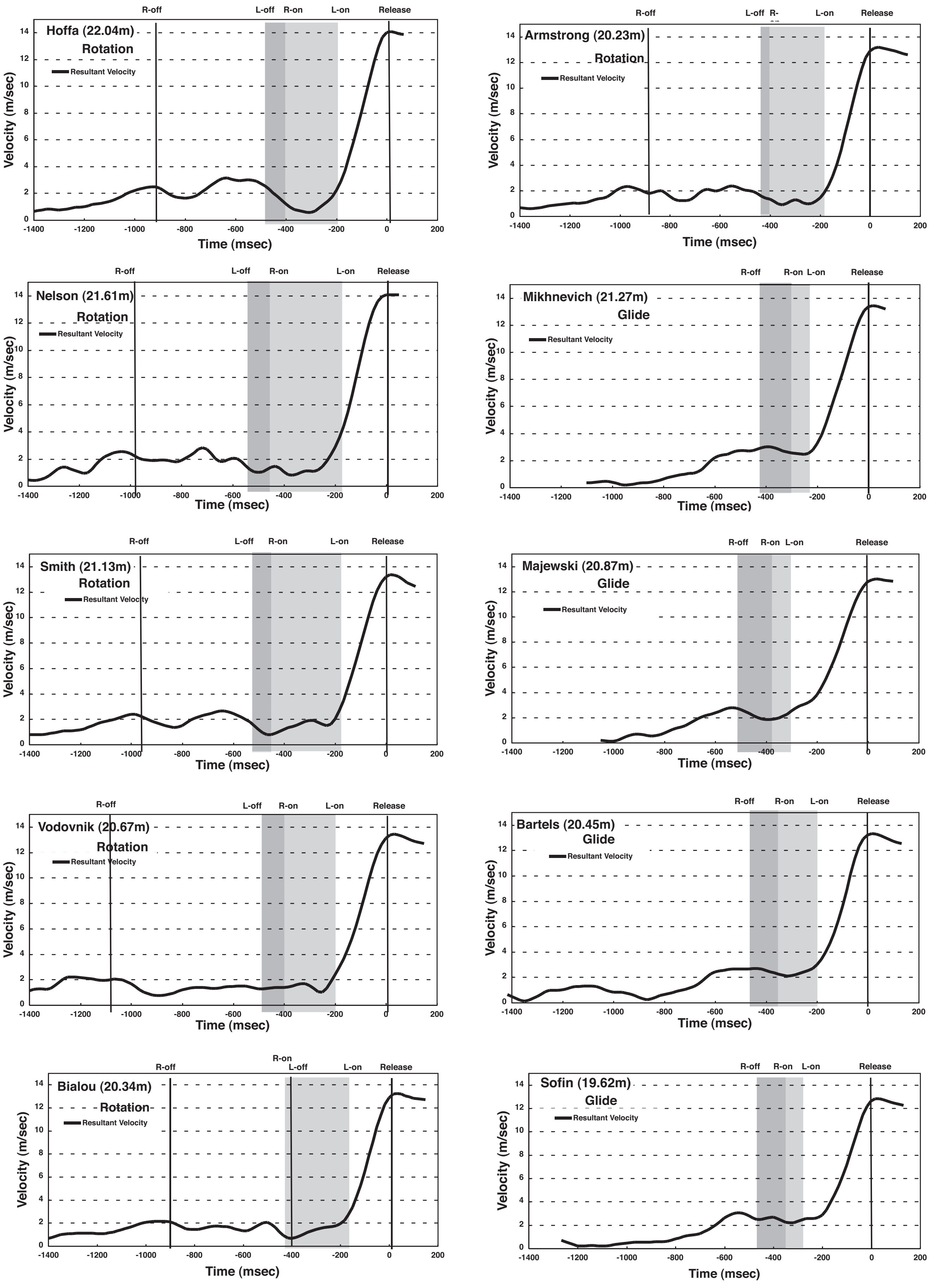

Figure 2: The time course of shot velocity (Only the resultant velocity is shown.)

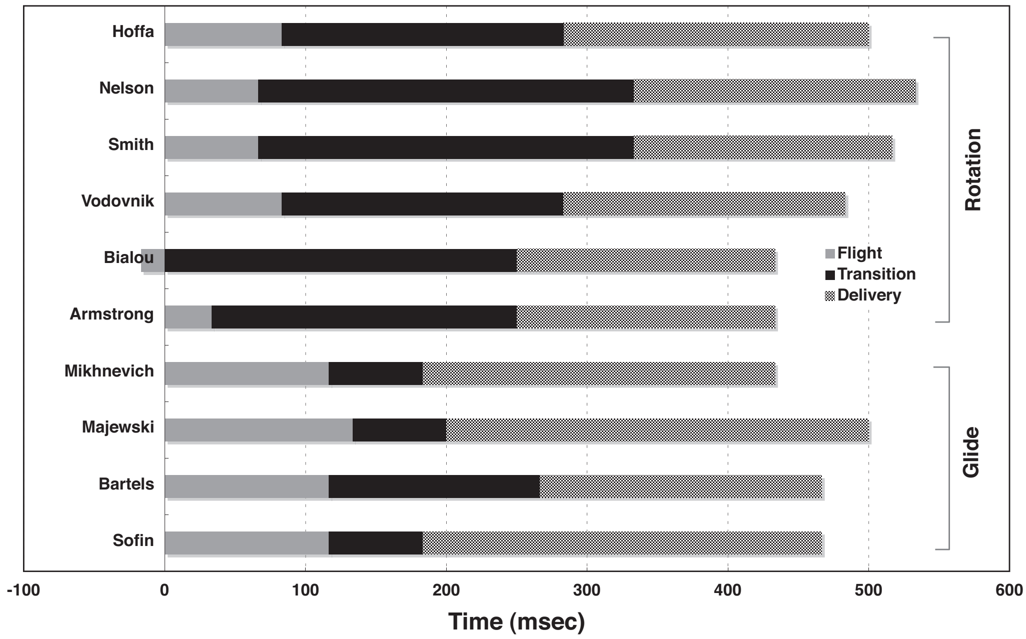

Figure 3: Duration of each movement phase from flight to release

Time course of velocity of the shot

The shot velocities for all three medalists show the typical time course pattern as described above.

Linear Momentum of the putter

For Hoffa and Mikhnevich, the resultant linear momentum increases gradually and peaks at the end of the preparation phase. Only Nelson shows a peak during the transition phase. After the peak, the momentum decreases toward the delivery. The peak value of the resultant linear momentum of Hoffa (368.9 kg m/sec) surpassed that of Nelson (297.5 kg m/sec) and even that of Mikhnevich (346.9 kg m/sec), who was using the glide. Nelson shows a notch-like depression just before the L-on, corresponding to the reverse action of the upper body during the transition phase. Mikhnevich, on the other hand, maintains the linear momentum throughout the preparation for the final thrust. Hoffa shows a pattern that is midway between the other two. The two rotators show a second peak of linear momentum around the L-on.

At the start of the weight shift and acceleration of the body during the preparation phase, individual differences are seen in the contribution of each component of the linear momentum. The two rotators are characterised by the rightward component during the most of preparation phase. While Hoffa makes a forward (putting direction) drive, Nelson shows a small backward component. Nelson shows a small upward component in the start and a downward component in the latter half of the phase; for Hoffa, the downward component is remarkable in the middle of the phase. Mikhnevich's glide is characterised by the starting with a downward component to forward with upward component before the R-off.

In all three, the vertical component shows a moderate peak just before the flight phase and remarkably high peak just before the delivery.

Angular Momentum of the putter

Before R-off, the two rotators increase their whole-body angular momentum about the CM mainly in the upper body. After R-off, they maintain a higher level of angular momentum throughout the motion. Mikhnevich keeps a low level of angular momentum in contrast to the linear momentum. Only Mikhnevich shows a rapid uniform increase of angular momentum in the transition phase. During the preparation phase, Hoffa keeps the level of angular momentum of the lower extremity with a balanced generation from both the right and left legs. In contrast, while the level of angular momentum of Nelson's right leg was almost same as that of Hoffa, that of his left leg is remarkably higher and the sudden increase corresponds to the marked peak of the angular momentum of the lower extremity and the increase of the whole body's angular momentum.

Trunk inclination and torsion angle

Figure 5 shows the forward - backward inclination

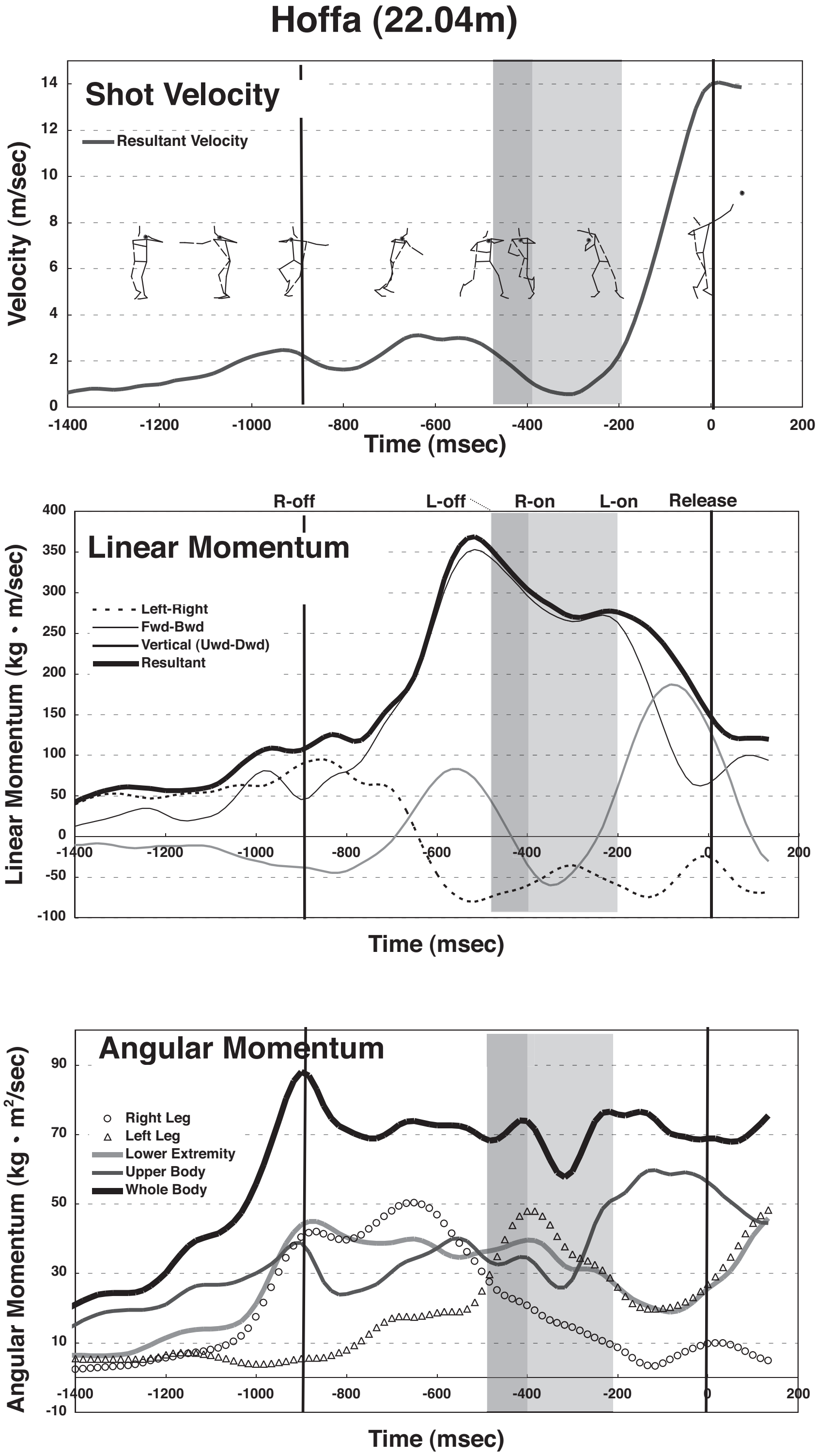

Figure 4a: Time course of shot velocity, linear momentum and angular momentum for Reese Hoffa

within the sagittal plane and the angle of torsion of the trunk. For Mikhnevich, both the inclination and torsion angle gradually increase from about 100msec before the R-off. Then the trunk inclination changes from horizontal to upright and reaches its peak at just before the release. The torsion angle peaks during flight phase. Hoffa and Nelson start their turns in a more upright trunk position. Their trunks tilt forward mostly during the flight phase and increase to a peak just before the release. Nelson leans more forward during preparation phase than Hoffa or Mikhnevich. It is common among the three that the trunk inclines backward before release and it rapidly reverses toward the release.

The trunk torsion of Hoffa reaches its minimum before R-off; for Nelson, it reaches the minimum late in flight phase. Hoffa and Mikhnevich's winding motion (increase

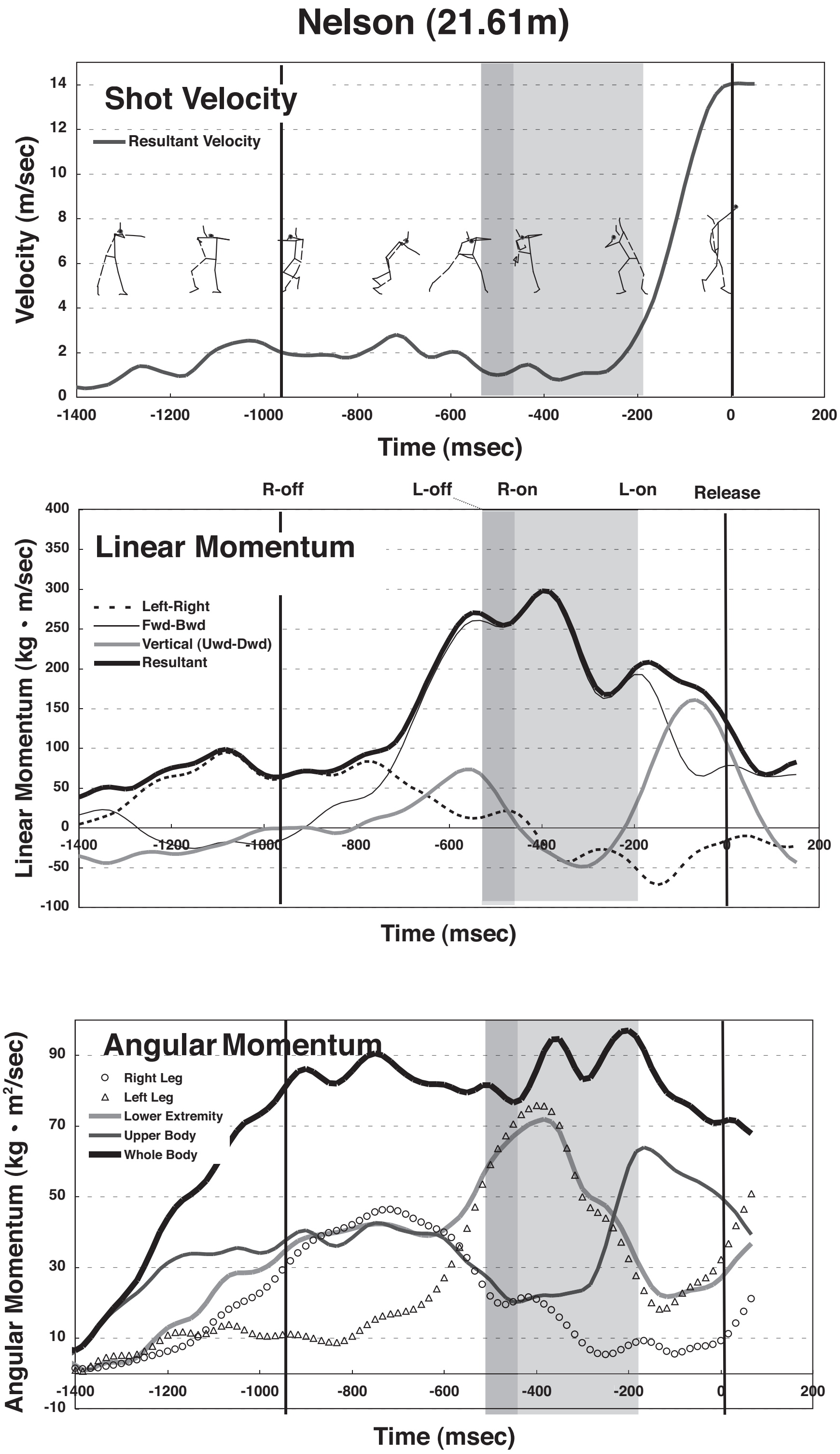

Figure 4b: Time course of shot velocity, linear momentum and angular momentum for Adam Nelson

of torsion) progresses at 121.3º/sec and 141.7º/sec respectively; that of Nelson increases more rapidly at 285.2º/sec. The recoil of the torsion begins in the flight phase in Mikhnevich and in the first half of transition phase in Hoffa and Nelson. The timing of increase of torsion coincides with the It and is more intensive in rotation technique than in the glide. Nelson shows a more rapid recoil (221.2º/sec) than Hoffa (190.8º/sec) and Mikhnevich (140.8º/sec).

Discussion

With regard to securing a maximal acceleration range of the shot, it is clearly disadvantageous to be short. It is reported that the body height of the champion Hoffa is 182cm, making him probably the shortest men's shot put

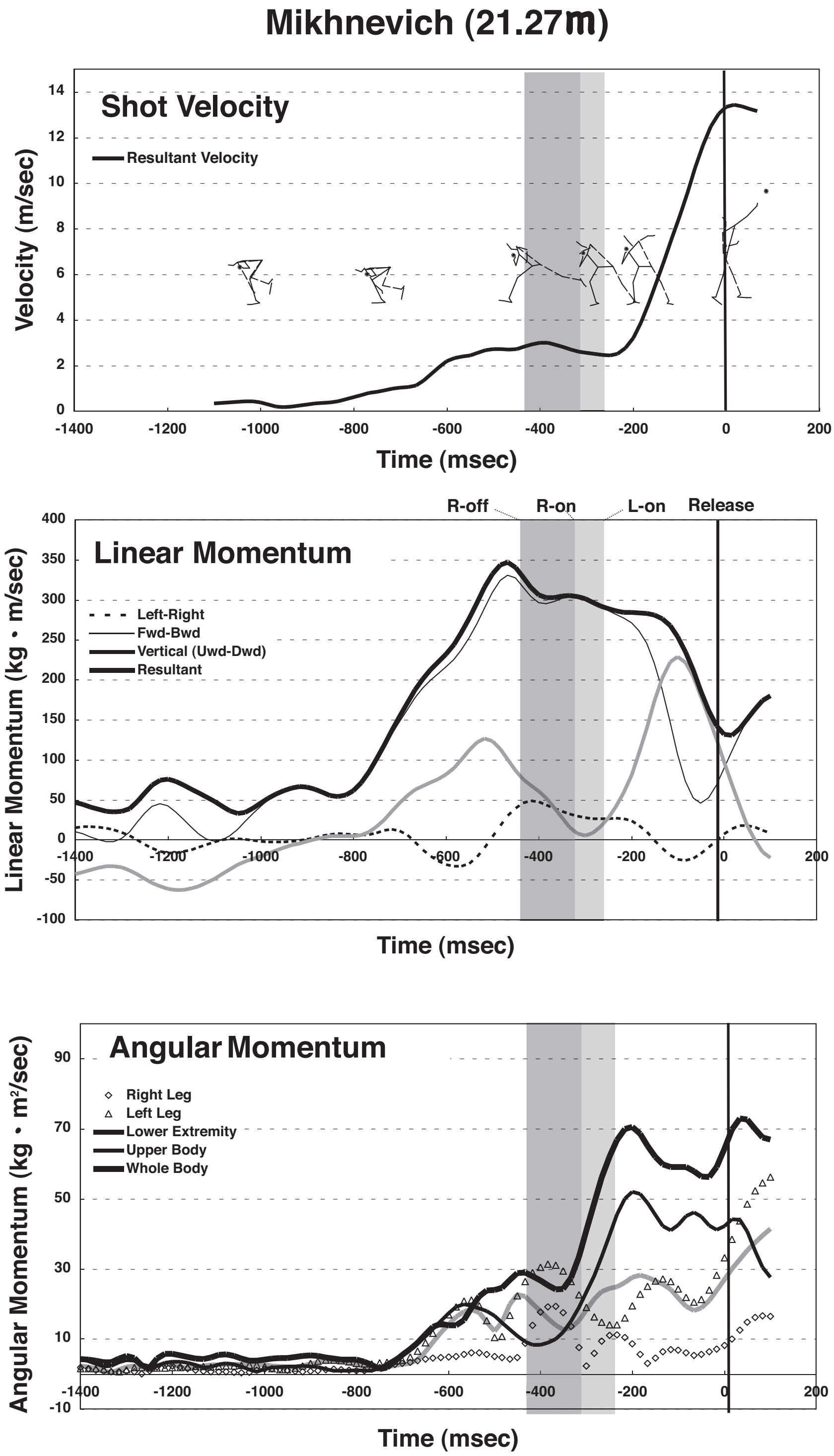

Figure 4c: Time course of shot velocity, linear momentum and angular momentum for Andrei Mikhnevich

world champion ever. Nelson and Mikhnevich are 183cm and 201cm respectively[11]. The notion that the rotation technique is more suitable for smaller putters has been confirmed by the results of Hoffa and Nelson. However, their technical excellence is also a key to their success.

The official results correlate significantly with the velocity at release. Some fluctuations can be related to other factors such as angle and position of release.

Because most of the shot acceleration is executed in delivery, the preceding phases should be aimed at ensuring the best conditions for maximising the final acceleration. The body position and the state of the musculature to be incorporated in the final movements are important and the energy storage within athlete-shot system is critical. The acceleration never occurs from the shot alone; there must be a source of energy. In past studies, the researchers' attention has been paid mainly to the acceleration of shot itself, even in the flight and

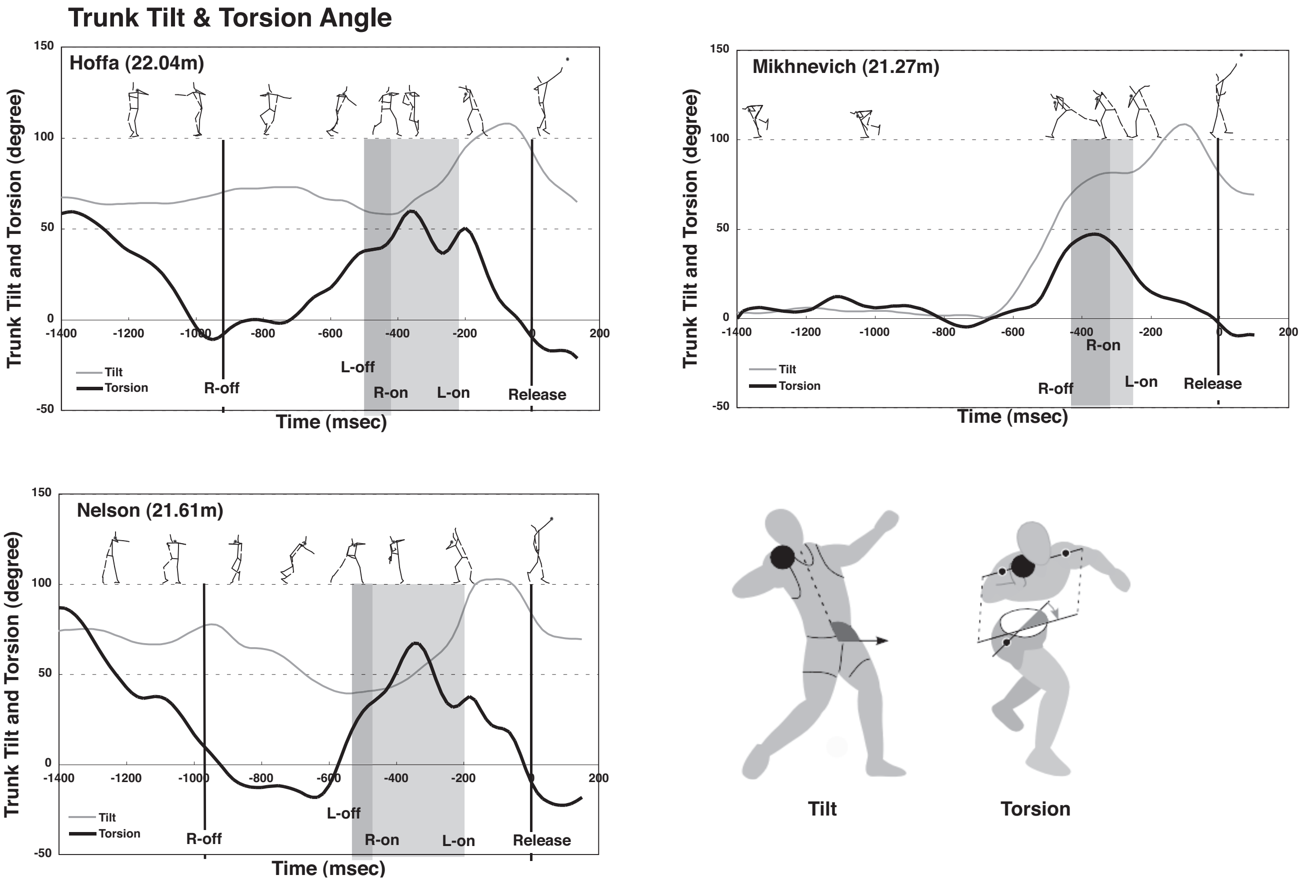

Figure 5: Forward - backward trunk inclination and the angle of torsion of the trunk (These parameters indicate tilting angle of trunk within sagittal plane relative to the horizontal axis and relative precedence of hip axis rotation to the shoulder axis rotation about longitudinal axis of trunk.)

transition phases. Luhthanen et al. pointed out the need of achieving an increase in the speed of the shot during the flight phase[5)]. From the viewpoint of the reduction of loss of shot velocity, Coh & Stuhec recommend keeping flight phase shorter[12)]. But the argument of how to secure the energy for acceleration has hardly been made. Although, a few researchers mentioned the importance of the momentum of the athlete-shot system[2),6),13)], we cannot find a study that showed it experimentally.

In the present study, the fall of the shot velocity during the flight and transition phases is more remarkable in the rotation than in the glide. This supports the results of the earlier reports. This slowdown of shot velocity corresponds to the right foot grounding. Especially in the rotation technique, this breaking motion coincides with the backward returning motion of the upper trunk. This seems to result in the dissipation of the shot velocity. However, simultaneous generation of angular momentum and a preparative configuration of body segments can be seen.

Analyzing the system acceleration of the three medallists in detail, we see that Mikhnevich, using the glide, depends on the linear momentum to store energy in the whole system. However, Hoffa shows the same level of peak resultant linear momentum as Mikhnevich. It is suggested that both linear and angular momentum are important, even in the rotational technique. The two rotators both show higher angular momentum than Mikhnevich.

Hoffa generates higher linear momentum from the effective weight shift to the putting direction and the push off. Then he skilfully suppressed the loss of the linear momentum that he got in the preparation phase and reaches the delivery. The two rotators show second peak of linear momentum around L-on. This seems to be related to the left leg swing of the transition phase. Actually, Nelson, with his marked second peak, is characterised by an intensive wide swing of left leg.

From the time course of each component of momentum we see that the higher angular momentum of the rotators after the second half of the preparation phase seems to be related to the motion of the lower extremity. In particular, Nelson keeps higher angular momentum throughout the preparation. Nelson who shows marked dissipation of linear momentum during transition phase adversely increases the angular momentum. It seems to be closely related to the intensive swing of left leg during the transition. The deep forward leaning angle of the trunk from before R-on to the transition seems to secure the range of motion of the left leg for a wide whipping motion. It is suggested that the leg movement causes the conversion of momentum from the leg to the trunk and a steep increase of the angular momentum of the lower extremity and provides trunk torsion as a result. Actually, the velocity of Nelson's trunk torsion increase is more than two times of that of Hoffa and Mikhnevich. This torsion can stretch the abdominal and back muscles just before the final thrust and ensure the intensive upper trunk rotation during the last phase of delivery. Nelson seems to be dependent more upon trunk torsion than Hoffa and Mikhnevich. It is speculated that Nelson most actively utilises the stretch-shortening cycle of trunk musculature. His remarkable wide swing of left leg seems to be the source of kinetic energy for this intensive torsion.

The participation of angular momentum and sideward acceleration — the advantage of rotational technique — can be considered as a disadvantage for coordinating the body balance. Hoffa eliminates this trade-off with a continuous linear acceleration of the CM from the back of the circle to the release point; standing without much dissipation of angular momentum of body in comparison with the glide technique. Actually, his linear momentum reaches a level that exceeds not only that of Nelson but, surprisingly, that of Mikhnevich the glider.

The backward trunk inclination during the delivery is caused by precedence of the driving pelvis, but it rapidly reverses toward the release. It is suggested that this forward-backward rotation of the trunk reinforces the final trust, cooperating with the linear translation and the recoil of the trunk torsion.

Conclusions

The results of the present study show:

1:While the release velocity is the main determinant of performance, some fluctuations can be related to other factors such as angle and position of release.

2:With reference to system acceleration, there are technical variations even within the rotational style: Hoffa utilises both linear and angular momentum of body to a great extent; in contrast, Nelson seems to emphasise angular momentum.

3:Mikhnevich, using the glide technique, keeps a higher level of linear momentum of the whole body from the push off of the glide to just before the final thrust.

4:Shot velocity alone is not enough to explain the process of acceleration. Whole-body momentum is gained or maintained even when there is a marked decrease of shot velocity during flight and transition phases of the rotation technique. It is suggested that the acceleration of athlete-shot system is the key factor ensuring the source of energy for delivery. It can be proposed that the aim of the preparation for the delivery is to accelerate the whole body and secure favourable body configuration rather than to accelerate the shot itself.

Please send all correspondence to:

Keigo OHYAMA BYUN：
1-1-1 Ten-noudai, Tsukuba, Ibaraki, Japan 305-8574
Graduate School of Comprehensive Human Sciences
(Inst. Health & Sport Sciences)
University of Tsukuba.
E-mail: ohyama@taiiku.tsukuba.ac.jp

REFERENCES

1) HEGER, W. (1974) Is the rotation technique better? Track Technique, 58, 1849.
2) ZATSIORSKY, V.M. (1990). The biomechanics of shot putting technique. In: Proceedings of the First International Conference on Techniques in Athletics, Vol. 1 G.P. Brüggemann & J.K. Rühl (Eds) (pp.118-125). Köln: Deutsche Sporthochschule.
3) PYKA, I. & OTRANDO, B. (1991). National Strength & Conditioning Association Journal, 13 (1) 6-9 and 83-88
4) GRIGALKA, O. (1985) In: J. Jarver (Ed.), The throws: contemporary theory, technique and training, 3rd ed (pp. 59-64). Los Altos, Calif.: Tafnews Press.
5) LUHTANEN, P.: BLOMQVIST, M. & VANTTINEN, T. (1997). A comparison of two elite shot putters using the rotational shot put technique. New Studies in Athletics, 12 (4) 25-33.
6) HAY, J.G. (1993). Biomechanics of Sports Techniques,

4th ed. Englewood Cliffs, NJ: Prentice-Hall.
7) SCHLUTER, W. & NIXDORF, E. (1984). Kinematische Beschreibung und Analyse der Diskuswurftechnik. Leistungssport, 6, 17-22.
8) ABDEL-AZIZ, Y. & KARARA, H. (1971). Direct linear transformation from comparator co-ordinates into object space co-ordinates. In: Proceedings of ASP/UI symposium on close-range photogrammetry (pp. 1–18). Falls Church, VA: American Society of Photogrammetry.
9) WINTER, D.A. (1990). Biomechanics and motor control of human movement (pp. 41-43). New York: John Wiley and Sons Inc.
10) AE, M.; TANG, H.P. & YOKOI, T. (1992). Estimation of inertia properties of the body segment in Japanese athletes. In: Society of Biomechanisms (Eds.), Biomechanisms 11 (pp. 23-33). Tokyo: University of Tokyo Press.
11) IAAF (2007) http://www.iaaf.org
12) COH, M. & STUHEC, S. (2005). 3-D kinematic analysis of the rotational shot put technique. New Studies in Athletics, 20 (3), 57-66.
13) BARTONIETZ, K.E. (1994). Rotational shot technique. Track and Field Quarterly Review, 94 (3), 18-29.