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Comparative Biomechanical Analysis of the Rotational Shot Put Technique

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A B S T R A C T

The study aimed to establish the modalities of the rotational shot put technique of two elite shot putters with substantially different constitutional characteristics. A biomechanical analysis of the technique was carried out using the APAS 3-D kinematic system, whereby a 15-segment model of shot putters was defined by 18 reference points. To enable the calculation of the kinematic and dynamic parameters, independent routines were programmed by the Matlab software. Anthropometric characteristics were established on the basis of 15 variables measured by the International Biological Programme (IBP) procedure. The results of the study revealed some differences between the athletes in terms of their mesomorphic constitutional component, body mass index, circular measures of the lower and upper extremities and the muscular, fat and bone mass. The technique models of both shot putters differ mostly in terms of the following kinematic and dynamic parameters: absolute release velocity, height of release, maximum angular velocity of the elbow of the throwing arm, trajectory of the centre of gravity of the body and the shot, torsional rotation of the shoulder axis relative to the hip axis, maximum force applied to the shot, kinetic energy and the kinetic energy differential of the shot.

***Key words**: shot-put, technique, model, anthropometrics, kinematics*

Introduction

The rotational shot put technique involves extremely complex movements performed at a high speed within a very limited space. The distance thrown (competitive result) is defined primarily by the path on which force is applied to the shot which is manifested in the release velocity, the angle of release and the height of release[2,5,8–10,12–14,16]. The height of release and the amplitude of the path of the shot's acceleration are determined by genetic-anthropometric factors – primarily body height, position of the centre of gravity and arm length. From the point of view of biomechanics, taller shot putters have an advantage over shorter ones. The angle of release is the ratio between the horizontal and vertical velocity in the release action. The shot putter has to optimise the angle of release, the release velocity and the height of release so as to achieve the maximum throwing distance. The shot put result (d) may be physically defined by the following formula on the assumption that air resistance is disregarded:

$$d = R_D + \frac{v_R^2 \sin(2\alpha_R)}{2g}\left(1+\sqrt{1+\frac{2gh_R}{v_R^2 \sin^2(\alpha_R)}}\right)$$

v_R – release velocity
α_R – angle of release
h_R – height of release
g – gravitational acceleration
R_D – release distance
d – distance thrown

The rotational shot put technique consists of rotational and linear movement sequences that have to be rhythmically interconnected. According to the biomechanical laws of motion, the principle of the sequential activation of segments and the principle of the co-ordination of particular impulses are applied[8]. Individual muscles are involved in the movement following the principle of parallelism and the principle of sequentiality. Parallelism is manifested in the synchronous involvement of individual muscle groups in the movement. Sequentiality means that muscles take part in the movement following the proximal-distal sequence. The initial movement is generated by the muscles of the lower body segment (legs) and the final movement by the muscles of the upper body segment (arm-hand). The primary power is gen-

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erated in the form of ground reaction forces as a result of the action of the lower extremities. It is characteristic of the rotational shot put technique that, when muscles take part in movement, their joints first move away (eccentric muscle contraction) and then closer (concentric muscle contraction). The efficacy of the eccentric-concentric muscle activity depends on the successive and coordinated proximal-distal sequence of muscle chains[13,15,16]. In addition to the correct muscle sequence, the path on which force is applied to the shot also plays an important role in the rational technique. Anatomic characteristics exert the strongest influence on the trajectory of the shot movement. The length of the trajectory is defined by the initial position of the shot putter, the height of the centre of gravity and the height of release. The height of release for elite shot putters is 220–235 cm[8,10,17]. According to studies so far undertaken[1,2,5,8–10,13,16], the release velocity is the most important factor of the shot put result. While the height of release and the angle of release are relatively constant variables, the release velocity can be improved considerably by proper training. In theory and practice, there is always an ongoing question of how to link up individual segmentary movements to eventually maximise the shot velocity. Shot put is an extremely complex and dynamic stereotype requiring the optimal interaction of movements of individual segments. The international competitive arena of recent times has increasingly been characterised by the domination of the rotational shot put technique (http://www.iaaf.org, 2005) which obviously facilitates the exploitation of a higher level of athletes' individual characteristics and abilities.

The aim of this study was to establish the modality of the rotational technique of two elite competitors with completely different anthropometric characteristics. Hypothetically, two specific rotational technique models defined by various kinematic and dynamic parameters can be expected. As a rule, the optimal technique model is an integration of anthropometric characteristics, the quality of biomotor abilities and the degree of automatisation of the movement stereotype. The study analysed the following: single-support phase, flight phase and double-support phase, release phase, release velocity, release angle, height of release, dynamics of shot velocity and the shot putter's centre of gravity, shot movement trajectory, angle between the hip and shoulder axes as well as the angle of the elbow and shoulder during release action. The anthropometric characteristics of both athletes were established by means of a set of 15 variables measured by the International Biological Programme (IBP) procedure. The measuring was carried out immediately before the competition by a professionally qualified person.

Methods

The measuring and biomechanical analysis of the rotational shot put technique of two elite shot putters (M. V. – age 28, height 1.95 m, mass 168.5 kg, BMI (body mass index) = 44.5; personal record 20.76 m; H. A. – age 26, height 1.85 m, mass 120.2 kg, BMI = 35.1, personal record 20.02 m) took place in May 2005 at an international athletic meeting held in Slovenska Bistrica, Slovenia. The competitors put the shot with their right arm. Six attempts of each competitor were recorded and only the best throw was included in the final analysis. Recordings were made with two synchronised cameras (SONY DVCAM DSR-300 PK) where the angle between the optical axes of the two cameras was 90°. The camera frequency was 50 Hz and the resolution 720 × 576 pixels. The analysed area of the circle was calibrated with a 1 m × 1 m × 2 m reference scaling frame and the calibration was based on eight reference corners. The length of the analysed movement was defined by the »x« axis, the height by the »y« axis and the depth by the »z« axis. The APAS 3-D software (Ariel Dynamics Inc., San Diego, Ca.) was applied to determine the points on the digital video recordings and transform the 2x 2-D data into 3-D. The 15-segment model of the shot putter's body was digitized and defined by 18 reference points. The eighteenth point was defined by the centre of the shot. The segments of the model represented parts of the body, linked with point-like joints. The masses and centers of gravity of the segments as well as the centre of gravity of the body were calculated by the anthropometric system[4].

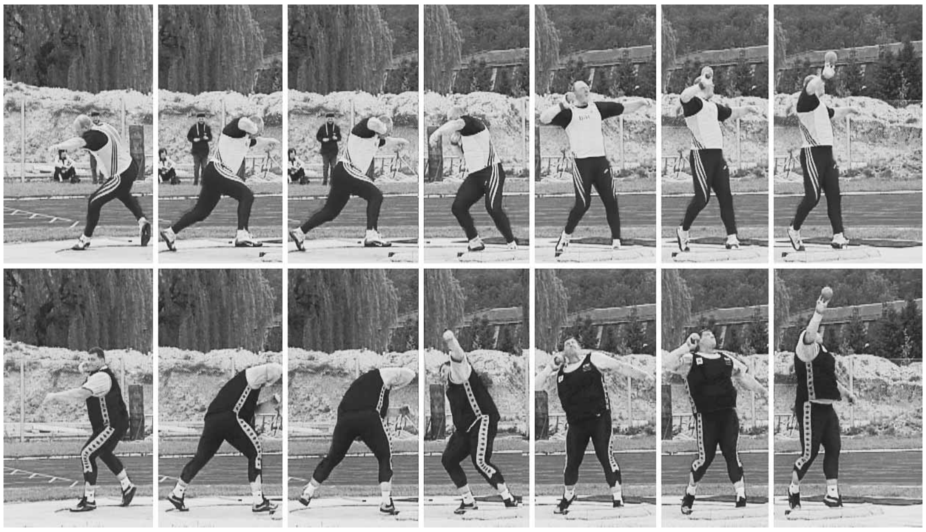
To calculate the parameters independent routines were programmed by the Matlab software and, where appropriate, they were smoothed with adequate cut-off frequencies and the orders of the Butterworth filter. The parameters were always calculated from raw data, while some of them were filtered subsequently. In all cases both versions of the parameters are presented – those calculated from the raw data and the filtered ones. The calculated parameters are the following: horizontal velocity (VX), vertical velocity (VY), absolute release velocity (V_R), height of release (h_R), angular velocity in the elbow of the release arm (EV), release distance (R_D), release angle (α_R), maximum force applied to the shot, lowest point of the shot, height of the shot landing (HL), maximum shot energy, side view and top view of the trajectory of the centre of gravity and trajectory of the shot, relative angle of the hip axis in relation to the shoulder axis, the development of shot energy and its time differential representing the power applied to the shot.

- The technique was defined by the following phases (Figure 1) that were identified via computer video analysis with a resolution of 20 ms:

- Initial stance (A1) – first double support phase – preparation for a throw with a preliminary swing – the competitor faces away from the direction of the throw.

- Entering the turn (A2) – this phase starts at the end of the double support phase and continues with the first single support phase on the left foot.

- Flight phase (A3) is defined as the transition from the left to the right foot near the centre of the circle; the end of the flight phase is at the same time the beginning of the second single support phase.



A1 A2 A3 A4 A5 A6 A7

Fig. 1. Phases of the rotational shot-put technique.

- The second single support phase starts when the right foot is placed on the ground (A4) and ends at the instant the left foot touches the front part of the circle.
- In the second double support phase (A5, A6, A7) the final release action of the shot put is performed.

The anthropometric measurements were taken by a professionally qualified person two hours before the competition. The anthropometric status of both athletes was established on the basis of 15 variables measured by the standard procedure of the International Biological Programme (IBP). The indexes of muscle, fat and bone tissues were calculated using Matiegka's method.

Results and Discussion

The anthropometric characteristics delineating the constitution of the shot putter largely define his technique model[1,8,16]. According to Sheldon's somatotypology, shot putters belong to the mesomorphic constitutional type which is characterised by increased mass and height as well as pronounced circumferences of the lower and upper extremities, diameter of the knee and ankle joints and diameter of the elbow and wrist. The athlete M.V. is a typical representative of the pronounced mesomorphic constitution with a high body mass (168.5 kg), height (1.95 m) and circumferences – particularly the thigh (85.4 cm) and calf (53.8 cm) – Table 1.

His BMI (body mass/body height^2) is 44.3, thus deviating from some of the most typical representatives of the modern rotational shot put technique (B. Oldfield – BH 1.92 m, BM 124 kg, BMI = 33.6; Godina – BH 1.93, BM 118 kg, BMI = 31.6; M. Halvari – BH 1.90 m, BM 140 kg, BMI = 38.8; R. Barnes – BH 1.94 m, BM 137 kg, BMI = 36.3). A high body mass offers an advantage in the final phase of the shot release. On the other hand, it represents a handicap when generating shot velocity in the rotation phases and in realising a sufficiently high torsion of the hip axis relative to the shoulder axis in the final shot acceleration phase.

TABLE 1
ANTHROPOMETRIC CHARACTERISTICS OF THE ATHLETES M.V. (OR = 20.76 M) AND H.A. (OR = 20.02 M)

Variable	Unit	M.V.	H.A.
Body height	M	1.95	1.85
Body mass	kg	168.5	120.2
BMA (AT/AV^2)		44.3	35.1
Circumference of upper arm	cm	46.7	39.5
Circumference of forearm	cm	37.2	34.7
Circumference of thigh	cm	85.4	72.3
Circumference of calf	cm	53.8	46.1
Shoulder width	cm	45.9	45.6
Pelvis width	cm	36.4	31.1
Elbow diameter	cm	9.0	8.1
Wrist diameter	cm	6.7	6.7
Knee diameter	cm	11.9	11.5
Ankle diameter	cm	9.3	8.7
Skin fold of upper arm	mm	17.4	9.8
Abdominal skin fold	mm	40.0	32.2
Thigh skin fold	mm	18.4	19.6
Share of fat mass	%	17.2	16.7
Muscle mass (Matiegka)	kg	84.0	58.1
Share of muscle mass	%	49.4	48.4
Bone mass (Matiegka)	kg	21.5	19.4
Share of bone mass	%	12.7	16.2
Ectomorphic component		–2.9	–1.1
Mesomorphic component		10.8	8.5
Endomorphic component		7.0	5.9

TABLE 2
KINEMATIC PARAMETERS OF THE ROTATIONAL SHOT PUT TECHNIQUE (M.V. AND H.A.)

Parameter	M.V.	H.A.
Official result	20.30 m	19.06 m
Release velocity (V_R)	13.95 m.s^{-1}	12.60 m.s^{-1}
Horizontal release velocity (VX)	11.44 m.s^{-1}	10.38 m.s^{-1}
Vertical release velocity (VY)	7.99 m.s^{-1}	7.15 m.s^{-1}
First double support phase T1–T2	0.58 s *	0.50 s *
First single support phase (T2–T3)	0.56 s *	0.58 s *
Flight phase (T3–T4)	0.04 s *	0.04 s *
Second single support phase T4–T5	0.24 s *	0.22 s *
Second double support phase T5–T6	0.10 s *	0.12 s *
Flight release phase T6–T7	0.06 s *	0.02 s *
Release angle (α)	34.9 °	34.6 °
Height of release (h_R)	2.25 m	2.02 m
Release distance (R_D)	0.24 m	0.25 m
Path on which force is applied to the shot in the final phase (DXY)	1.66 m	1.50 m
Average angular velocity in the elbow of the throwing arm (EV)	708° / sec.	640° / sec.
Maximum angular velocity in the elbow of the throwing arm (MEV)	1881° / sec.	2030° / sec.
* filtered data	1532° / sec.	1450° / sec.
Maximum force applied to the shot	653 N	644 N
Lowest point of shot	1.32 m	1.17 m
Shot flight distance (FD)	20.06 m	18.81 m
Height of shot landing (HL)	5.5 cm	5.5 cm

* parameters were measured using computer aided video analysis with 20 ms accuracy.

The other subject of our study, H.A., has a less pronounced mesomorphic constitution with a lower body mass (120.2 kg) and height (1.85 m). On the other hand, his diameters of the shoulder, elbow and knee are very pronounced and the percentage of his bone mass is high (16.2%). Both athletes have a similar percentage of muscle and fat mass. The fat mass of M.V. is absolutely excessive (17.2%) and manifested in the abdominal skin fold (40.0 mm). The abdominal skin fold represents ballast tissue which generally negatively affects the motor efficiency and the technique of the movement stereotype. The athlete's skin fold of the upper arm, representing an extremely important segment in the final phase of the shot acceleration, is also relatively thick (17.4 mm).

The difference between the two athletes in the shot put result is 1.24 m. Table 2 shows the key kinematic parameters generating this difference in the competitive result. M.V.'s release velocity (13.95 m.s^{-1}) and height of release (2.25 m), which directly define the result, are considerably higher.

The release velocity is undoubtedly one of the major parameters of the technique and depends on previous phases, especially the final acceleration phase. The height of the release mainly depends on anthropometric characteristics (body height, arm length) and the shot put technique. The increase in the height of the release proportionally increases the distance thrown[8]. In addition to its direct correlation with the trajectory of the shot flight, the height of the release also affects the distance covered by the shot in the final acceleration and thus, indirectly, the stronger impulse of force – on the assumption that the lowest point of the shot is low enough. The athlete M.V. generated a 9.7% higher release velocity, thus exceeding the velocity of the athlete H.A. by 10.2%.

The mathematically calculated optimal release angle α_{opt} ranges from 40° to 43° and is calculated by the following formula:

$$\alpha_{opt} = \frac{1}{2}\arccos\left(\frac{1}{1+\frac{v_R^2}{gh_R}}\right)$$

The actual release angle, where the height of the release and the release velocity are taken into consideration, ranges from 31° to 36°. The release angles of our subjects are 34.9° and 34.6°. Linthorne (2001) found that release velocity decreases with an increasing release angle. It can thus be concluded that the release angle of M.V. is less optimal than that of H.A. A smaller release angle enables body segments to generate a higher shot acceleration. Analyses of results at major international competitions show that the values of the release angle vary substantially more in the rotational than the classical linear technique[8]. The reason lies in the stability and balance deviations in the rotational movement phase. Two functional systems are responsible for keeping one's balance, namely the reticular formation and vestibular core[10]. A lack of stability and balance in the rotational phase directly decreases the interaction of the lower and upper segments of the thrower's body. The release height and some external factors (adverse wind) impact on the release angle, but to a lesser extent than with javelin throws or discus throws.

The most important factor on which the training of technique and development of the explosive power can impact is the release velocity which directly depends on the throw impulse of the force $\int \vec{F}dt$:

$$\vec{v}_R = \frac{\int \vec{F}dt}{m},$$

where $\vec{F}$ is the force applied to the shot in time »t«. On the other hand, it may be claimed that it depends on the performed work:

$$v_R = \sqrt{\frac{2\int \vec{F}d\vec{s}}{m}}$$

where $\vec{s}$ is the path on which the force is applied to the shot. It may be established from these equations that the release velocity increases in two ways. First, by prolonging the time in which the force is applied to the shot or by prolonging the path, even though these two parameters correlate. Second, (and logically), by increasing the force. Even though the parameters of technique and power are interrelated, one may expect that the degree of force mainly depends on power, while distance and/or time during which the force is applied to the shot depends on the technique.

The final action of thrusting the shot in the direction of the throw starts by changing the relative angle of the shoulder axis in relation to the hip axis. Then through the torsion of the upper part of the body the putter applies additional force to the shot (Figure 2). This is seen in the diagram in the last 0.25 seconds before the shot release. The difference between the two competitors in this crucial part is substantial. Owing to the higher body mass and greater fat tissue in the upper part of the body, M.V.'s torsional rotation is substantially smaller than that of H.A. The difference is 30° (calculated from raw data) or 22° (filtered data).

It may be established that the release action of M.V.'s right arm is very efficient, manifesting itself in the parameter of maximal angular velocity of 1881° / sec. (filtered data: 1532° / sec.). It may be anticipated that the shot release velocity of M.V. is chiefly related to his exceptional explosive power of the upper extremities and trunk, as his result in a bench press is 260 kg. The athlete H.A. develops a maximal angular velocity of 2030° / sec. (filtered data: 1450° / sec.). The development of force applied to the shot differs between the two competitors even though the maximal force assessable by kinematics is very similar. M.V. develops a maximal force of 653 N, and H. A. 644 N (Table 2). In addition, the assessed maximal force before the release is 0.09 of a second for both athletes.

Although the position and/or path of the shot are two basic parameters and do not differ considerably at first sight, our analysis shows substantial differences between the two anthropometrically very different shot putters. If we concentrate first on the movement of the centre of gravity (Figures 3 and 4), we notice a higher position of the trajectory of the taller shot putter in the side view (according to expectations), which differs even more importantly in the initial and final phases of the release. The shorter and lighter shot putter (H.A.) starts the throwing action from a lower and more stable position, with a more pronounced bend in the hip and knee joints, while in the continuation the trajectory is very similar until the final release phase (Figure 3). There, the centre of gravity of the shorter and lighter competitor is considerably more advanced than that of the taller and heavier athlete (Figure 3). Moreover, his phase during which he keeps his balance after the release is shorter – otherwise he would cross the limit of the throwing circle.

Besides the difference seen in the side view, the difference shown by the top view is also interesting as the centre of gravity of the shorter and lighter shot putter moves much more »straightforwardly« in the direction of the throw than that of the taller and heavier athlete (Figure

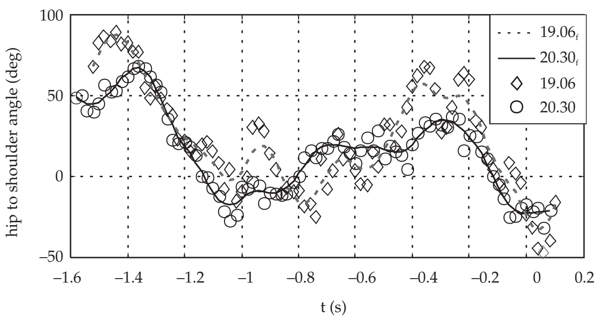


Fig. 2. Relative torsional rotation of the hip axis in relation to the shoulder axis. Diamonds and circles show rotations calculated from raw data, while the full and dashed lines show their filtered values. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

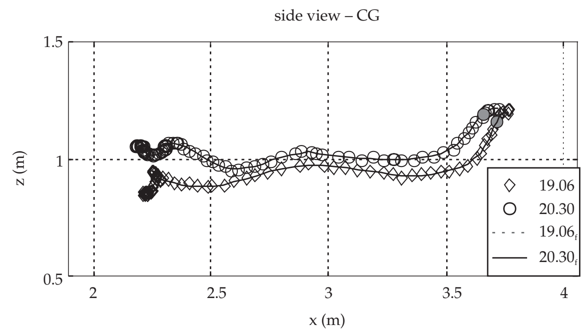


Fig. 3. Side view of the trajectory of the centre of gravity for both athletes. Diamonds and circles show the raw points of the trajectory, the full and dashed lines show the filtered ones. The dot shows the point of release. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

4). Owing to this, the shorter athlete's path of the centre of gravity is shorter. Again, this difference can be explained by physical parameters as the taller and heavier competitor has a greater moment of inertia. If he wants to achieve the rotation of the body around its axis, he has to »overcome« the greater moment of inertia and needs higher torque, which may be generated by the higher amplitude of the sideway movement of the centre of gravity. In this way he ensures a longer lever arm by swaying his body and moving sideways.

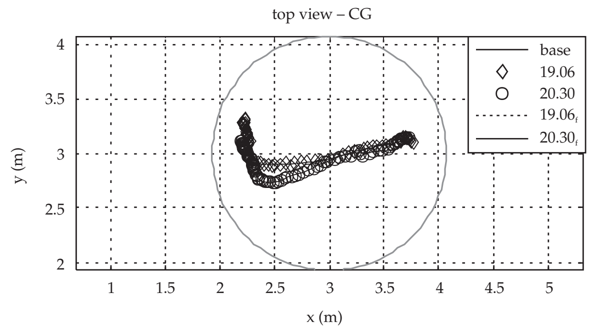


Fig. 4. Top view of the trajectory of the centre of gravity for both athletes. Diamonds and circles show the raw points of the trajectory, the full and dashed lines show the filtered ones. The dot shows the point of release. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

Even larger differences than in the movement of the centre of gravity are seen in the movement of the shot. It was already established that, at the beginning, the centre of gravity of the shorter and lighter athlete is lower and, consequently, this is even more evident in the shot movement (Figure 5). Therefore, the side view of the shot's trajectory differs considerably and it also features two pronounced »minimums« of the shot trajectory, while the trajectory of the heavier and taller athlete has only one.

The release point of the taller subject is 23 cm higher. Within the scope of the accuracy of our measurement, the shot release point of the two athletes does not differ in the horizontal plane in the direction of the throw (Figures 5 and 6).

Even though the centre of gravity of the shorter and lighter athlete (H.A.) in the top view covers a shorter distance than that of the taller and heavier athlete (M.V.), it can be established that the shot covers a longer distance mainly in the first double support phase, the first single support phase and the first flight phase.

A substantial difference between the compared subjects is also seen in the development of the shot energy (Figure 7) which correlates with the energy of the thrower-shot system. With a lower angular velocity of the rotation of the body around its axis, the taller and heavier thrower M.V. may have the same mechanical energy of the body. Consequently, his angular velocity of the rotation of the body around its vertical axis in the last acceleration phase is lower as his greater height and body

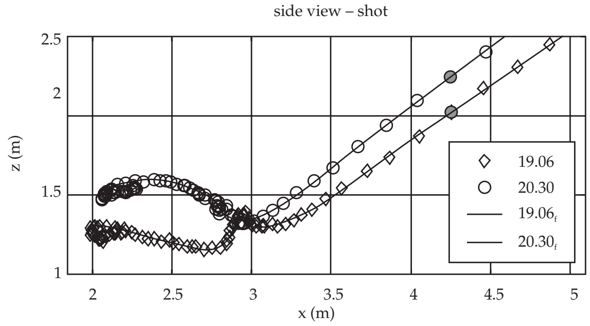


Fig. 5. Side view of the shot trajectory for both athletes. Diamonds and circles show the raw points of the trajectory, the full and dashed lines show the filtered ones. The dot shows the point of release. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

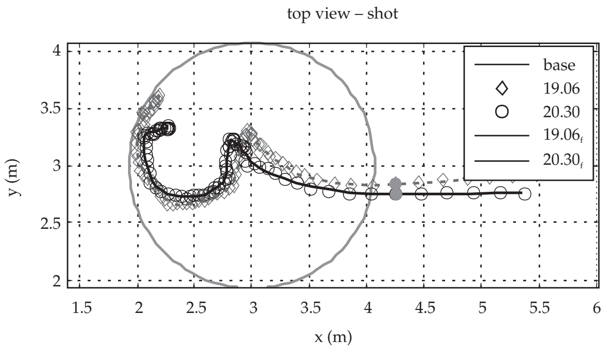


Fig. 6. Top view of the shot trajectory for both athletes. Diamonds and circles show the raw points of the trajectory, the full and dashed lines show the filtered ones. The dot shows the point of release. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

mass allow him this and/or he is capable of generating such velocity.

It is the above, combined with the higher amplitude of the shot release, that prolongs the time of the last accel-

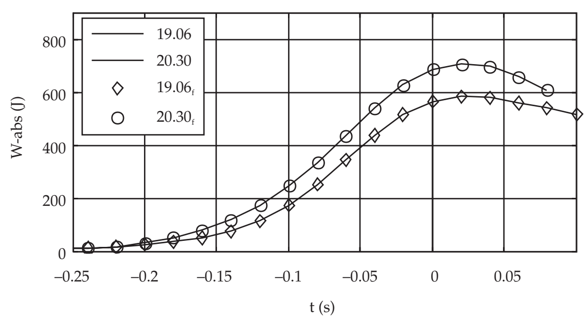


Fig. 7. Kinetic energy of the shot for both athletes. Diamonds and circles show the energy calculated from the raw data, while the full and dashed lines show its filtered value. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V. Note: The energy maximum is achieved immediately after the release point as a consequence of the problematic determination of the release point at the measurement frequency of »only 50 Hz« and data filtration.

eration phase. Therefore, the transfer of energy to the shot by the taller and heavier athlete may start earlier than with the shorter and lighter athlete (see Figures 7 and 8). It is the time differential of energy (Figure 8) that best demonstrates the increase in the energy, at the same time representing the mechanical power which the thrower applies to the shot.

In addition to this difference, two other differences exist which are also important. The heavier and taller competitor generates a substantially higher maximal energy (Figure 7) and considerably higher maximal differential of energy and/or power (Figure 8) since that of M.V. is 5.13 kW (kJ/s) and that of H.A. is »only« 4.68 kW (kJ/s).

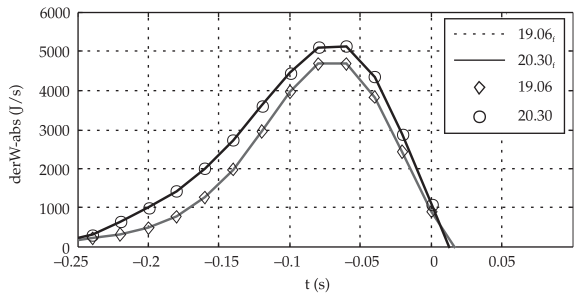


Fig. 8. Kinetic energy differential of the shot for both athletes. Diamonds and circles show energy differential calculated from the raw data, while the full and dashed lines show its filtered value. Key: 19.06 is the distance thrown by H.A.; 20.30 is the distance thrown by M.V.

Conclusion

Based on a comparative biomechanical analysis of shot put involving two shot putters with considerably different anthropometric characteristics the following may be concluded – despite the smallness of the sample. Anthropometric characteristics are important and they impact on the shot put technique and results. Large differences are seen in the trajectories of the movement of the centre of gravity and shot in all directions, directly correlating with the anthropometric characteristics – primarily body height and mass. In addition, an important difference was demonstrated in the torsional rotation of the upper body in the final shot thrusting action. The heavier thrower with more abdominal fat tissue is substantially less capable of exploiting the important kinetic chain of turning his shoulders relative to the hip axis. Moreover, the development of kinetic energy of the shot differs considerably. The final acceleration of the taller and heavier athlete lasts longer and thus he starts applying energy earlier than the shorter and lighter athlete. Moreover, the maximal force or transformation of the shot's kinetic energy by the heavier and taller thrower is higher, meaning that he applies more energy by time unit. The result is the higher final kinetic energy of the shot. Naturally, a similar release angle – which within the accuracy of our study is equal – results in a longer distance being thrown. Our results reveal a small difference in the maximal force applied to the shot, however, this may be ascribed to the numerical calculation methods and inadequacy of kinematics for assessing the second-order parameters. A similar trend was observed in the parameter of angular velocity in the elbow joint, which was due to the relatively low data capturing frequency. This indicates the higher velocity of the shorter athlete, which may be accounted for by his shorter forearm and upper arm.

R E F E R E N C E S

1. BARTLETT R, Biomechanics in Sport. (Blackwell Science Ltd, 2000). — 2. BARTONIETZ K, Track and Field Quarterly Review, 3 (1994) 18. — 3. BARTONIETZ K, BORGSTRÖM A, New Studies in Athletics, 4 (1995) 43. — 4. DEMPSTER W, Space requirements of the seated operator. (Wright-Petterson Air Force Base, Ohio, 1955). — 5. HUBBARD M, NEVILLE J, SCOTT J, Journal of Biomechanics, 34 (2001) 449. — 6. GEMER G, New Studies in Athletic, 1 (1990), 31. — 7. GOSS-SAMPSON M, CHAPMAN M, Journal of Sports Sciences, 21 (2003) 237. — 8. LANKA J, Biomechanics in Sport. (Blackwell Science Ltd, 2000). — 9. LINTHORNE N, Journal of Sports Sciences, 19 (2001) 359. — 10. LUHTANEN P, BLOMQVIST M, VANTTINEN T, New Studies in Athletics, 4 (1997) 25. — 11. LUKES D, Track and Field Quarterly Review, 3 (1989) 9. — 12. OESTERREICH R, BARTONIETZ K, GOLDMANN W, New Studies in Athletics, 4 (1997) 35. — 13. PALM V, Modern Athlete and Coach, 3 (1990) 15. — 14. RASMUSSEN, B, Spin to Win. Part 1 (2005). http://www.elitetrack.com/throws.html. — 15. ROBERTSON D, CALDWELL G, HAMILL J, KAMEN G, WHITTLESEY S, Research Methods in Biomechanics. (Human Kinetics, P.O. Box 5076, Champaign, IL, 2004). — 16. STEPANEK J, International Symposium of the Society of Biomechanics in Sport, Hellenic Sports Research Institute, Olympic Sports Centre of Athens, Greece (1989).

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KOMPARATIVNA BIOMEHANIČKA ANALIZA ROTACIJSKE TEHNIKE BACANJA KUGLE

S A Ž E T A K

Svrha studije bila je uspostavljanje uvjetnosti rotacijske tehnike bacanja kugle kod dva vrhunska bacača kugle znatno različitih konstitucijskih karakteristika. Biomehanička analiza tehnike provedena je koristeći APAS 3-D kinematički sustav, dok je 15-segmentni model bacača kugle definiran sa 18 referentnih točaka. Kako bi se omogućilo izračunavanje kinematičkih i dinamičkih parametara, programirani su nezavisni postupci Matlab softvera. Uspostavljene su antropometrijske karakteristike na temelju 15 varijabli mjerenih postupkom IBP (*International Biological Programme*). Rezultati studije otkrili su neke razlike između atletičara u odnosu na njihove mezomorfne konstitucijske komponente, indeks tjelesne težine, cirkularne mjere donjih i donjih ekstremiteta te mišićne mase, masnoće i koštane mase. Tehnike obaju bacača kugle razlikuju se najviše u odnosu na kinematičke i dinamičke parametre: brzina apsolutnog otpuštanja, visina otpuštanja, maksimalna kutna brzina lakta ruke koja baca, putanja centra gravitacije tijela i kugle, torzijska rotacija osi ramena prema osi kuka, maksimalna sila primijenjena na kuglu, kinetička energija te kinetička energija razlike izbačaja.