A KINEMATIC MODEL OF ROTATIONAL SHOT- PUT TECHNIQUE

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The purpose of the study was to identify some of the most relevant kinematic parameters defining the competition result in rotational shot-put technique. A biomechanical analysis was carried out on an example of an elite shot-putter, member of the Slovene national team, who had ranked 11th in the finals of the 2004 Olympic Games in Athens. The 3-D video system for kinematic analyses (APAS) was used. A 15-segment model of shot-putter consisting of 18 reference landmarks was defined. The results of the study showed that the top result in rotational technique depended on release velocity, optimal release angle, relation between rotational movement and final acceleration of the shot as well as angular velocity in the elbow and shoulder of the throwing arm. The key phases that ensure the correct rhythm and generate high release velocity of the shot are the following: flight phase, second single support phase and second double support phase.

KEY WORDS: shot – put, technique, model, kinematics

INTRODUCTION: Rotational shot-put technique is characterised by very complex movements performed at a high speed in a confined space. Many factors determine the results in this track and field event, of which the most important are morphological characteristics, motor abilities and technique. The distance thrown is determined by release velocity, angle of release, height of release and distance over which force is applied to the shot (Stepanek, 1989; Palm, 1990; Bartonietz, 1994). The height of release and amplitude of the path of the shot acceleration are determined by genetic factors, primarily by body height and arm length.Therefore, taller throwers have an advantage over shorter throwers. Release angle is a vector variable resulting from a combination of the horizontal and vertical forces in release action. The rotational shot-put technique consists of rotational and linear movement sequences that have to be rhythmically linked. Individual muscles take part in movement based on the principle of parallelism and the principle of sequentiality. Parallelism is manifested in synchronous involvement of individual muscle groups in movement. Sequentiality means that muscles take part in movement following the proximal–distal sequence. The initial movement is generated by the muscles of the lower body segment (legs), while the final movement is generated by the muscles of the upper body segment (arm–hand). Intially power is generated in the form of ground reaction forces as a result of the action of lower extremities. It is characteristic of the rotational shot-put technique that, when muscles take part in movement, first their joints move away (eccentric muscle contraction) and then they move closer (concentric muscle contraction). The efficacy of the eccentric–concentric muscle activity depends on the successive and co-ordinated proximal–distal sequence of muscle chains (Stepanek, 1989; Palm, 1990).
The purpose of this study was to identify some of the most relevant kinematic parameters of the rotational shot-put technique used by a Slovene elite shot-putter, whose personal record is 20.56 m and whose result of 20.04 m ranked him 11th at the 2004 Olympic Games in Athens. A number of kinematic variables were analysed they being: first double support phase (preparation for throw with preliminary swing – the athlete faces away from the direction of the throw), entering the turn (this phase starts at the end of the double support phase and continues with the first single support phase on left foot), flight phase is defined as the transition from the left to the right foot near the centre of the throwing circle, the second single support phase starts, when the right foot is set on the ground and ends at the instant the left foot makes contact with the front part of the throwing circle, the second double support phase the final release action of the shot-put is performed, release velocity, release angle, release height, dynamics of shot velocity and thrower's centre of gravity, shot movement trajectory, angle between hip and shoulder axes, and angle of the elbow and shoulder during release action.

METHODS: The measurements and the biomechanical analysis of the rotational shot-put technique of the Slovene national team member (age: 27 years, height: 1.95 m, body mass: 169.5 kg) were carried out in July 2004 during the preparations for the Athens Olympic Games. Eight throws were recorded during the testing. Recordings were made with two synchronised cameras (SONY DVCAM DSR-300 PK) fixed at an angle of 90° between their optical axes. A third camera (SONY TRV840E) was set at a height of 4 m, precisely above the throwing circle. In all three cameras the frequency was 50 Hz and the resolution 720 x 576 pixels. The analysed area of the throwing circle was calibrated with a 1 m x 1 m x 2 m reference scaling frame, and the calibration was based on eight reference edges. 3-D software APAS (Ariel Dynamics Inc., San Diego, Ca.) was used for establishing kinematic parameters of the technique. The 15-segment model of the thrower's body was digitized and defined by 18 reference landmarks.

RESULTS AND DISCUSSION: Based on the analysis of the basic kinematic parameters of rotational shot-put technique (Table 1) the following may be ascertained:

Table 1 Kinematic parameters of the rotational shot-put technique.

Parameter	Result
Official distance	19.58 m
Release (resultant) velocity	12.94 $m.s^{-1}$
Horizontal velocity	10.47 $m.s^{-1}$
Vertical velocity	7.61 $m.s^{-1}$
First double support phase	2.28 $m.s^{-1}$
First single support phase	1.67 $m.s^{-1}$
Flight phase	0.80 $m.s^{-1}$
Second single support phase	1.45 $m.s^{-1}$
Second double support phase	7.02 $m.s^{-1}$
Flight release phase	12.71 $m.s^{-1}$
Release angle	35.9 °
Release height	2.28 m
Release distance	0.21 m
Distance over which force is applied to the shot in the final phase	1.65 m
Average angular velocity in the elbow of the throwing arm	875 °/ sec.
Maximum angular velocity in the elbow of the throwing arm	1378 °/ sec.
Average angular velocity in the shoulder of the throwing arm	452 °/ sec.
Maximum angular velocity in the shoulder of the throwing arm	652 °/ sec.

The results of the athlete namely release velocity (12.94 $m.s^{-1}$), release angle (α = 36°), release height (2.27 m) and index of release height and body height (release height = 1.17), are comparable with the results obtained in some earlier studies (Stepanek, 1989; Palm, 1990; Luhtanen et al., 1997). Release velocity is undoubtedly one of the most important parameters of the technique and is generated by preceding phases, especially the second double support phase. Our subject had a release velocity of 12.94 $m.s^{-1}$ which is slightly less than some other best rotational shot putters (J. Godina – 13.44 $m.s^{-1}$, M. Halvari 13.16 $m.s^{-1}$, R. Barnes 13.53 $m.s^{-1}$ and K. Noen 13.05 $m.s^{-1}$).

The release angle of 35.9°, which with respect to his release velocity (12.94 $m.s^{-1}$) was an optimal value according to Linthorne's (2001) model. Generally, it may be established that release angles of some rotational shot-putters vary more than those of shot-putters using classic technique. This is due to the fact that during the rotational movement phase, deviations occur in terms of stability and balance. Two functional systems are responsible for keeping balance, namely reticular formation and vestibular nucleus. Lack of stability and balance in the rotational phase has direct effects on lower accuracy in the performance of the final shot acceleration phase.

The average velocity in the first double support phase was 2.28 $m.s^{-1}$, in the first single support phase 1.67 $m.s^{-1}$, in the flight phase 0.80 $m.s^{-1}$, in the second single support phase

1.45 m.s^{-1}, in the second double support phase 7.02 m.s^{-1} and in the flight release phase 12.71 m.s^{-1}. The final velocity of the shot at the moment of release was 12.94 m.s^{-1}. It may be established that the athlete starts moving with a rapid transition to a turn. Nevertheless, this velocity in the first single support phase decreased by 0.61 m.s^{-1}. Transition from a double support phase to a turn depends on morphological and motor abilities, especially co-ordination, balance, orientation in space, power, speed and agility of the thrower.

In the flight phase, which lasts only for 0.04 seconds, velocity decreases by another 0.87 m.s.$^{-1}$. This is also the lowest velocity of the shot in the entire trajectory of all six movement phases. As during the flight phase the thrower is not in contact with the ground, this phase cannot contribute to acceleration of the shot, which is why it has to be as short as possible. In this phase, the legs have to surpass the trunk and the shot as much as possible in terms of longitudinal rotation. A too long a flight phase may break the rhythm of movement of the thrower–shot system as a whole. In the second single support phase on the right leg the shot velocity increases by 0.65 m.s^{-1} and reaches 1.45 m.s^{-1}, accounting for only 12% of velocity in the final release phase.

Once the athlete sets his left foot on the ground at the front of the throwing circle, the second double support phase begins, playing a crucial role in efficient performance of release action. In this phase the velocity of shot increases rapidly – by 5.57 m.s^{-1} compared to the previous phase. In this segment of shot trajectory, the achieved velocity accounts for 55% of the maximum shot velocity at release. At the end of the second double support phase the shot velocity reaches 12.71 m.s^{-1}. Average velocity achieved in the double support phase accounts for 77% of the shot release velocity. The distance over which force is applied to the shot in the final acceleration phase is 1.65 m. Low position of the shot depends primarily on the angle of a strongly bent right knee, which is 115° in the case of our subject. The second double support phase is one of the key elements in the entire structure of rotational technique. The position of the trunk is important for generation of power at release, particularly the difference between the hip axis and the shoulder axis. The aim of this phase is to increase the torque between the shoulder axis and the hip axis. The athlete achieves this by rotating the lower part of his body. The higher the torsion of the body, the stronger the accumulation of potential (elastic) energy that will be released at the release phase.

Planting of the right foot in the middle of the throwing circle is the most important factor of efficient transfer of velocity from rotational movement to release velocity of the shot. Therefore, a thrower has to plant his right foot firmly on the ground. Amortisation in the right knee has to be as short as possible. In this phase velocity is still declining, as the centre of gravity is located behind the application point of support. At the instant the right foot is planted on the ground, the velocity of the shot is 1.38 m.s^{-1}. After the amortisation, pivoting takes place followed by a push off with right leg and transference of weight of the thrower–shot system to the front left leg. When weight is transferred from the right to the left leg, the shot velocity is 3.01 m.s^{-1}. Fast planting of the front left leg stops the rotation of the left side of the body and shoulder girdle, and consequently increases the rotation of the right side of the body. To prevent the angular velocity of hips from decreasing, the rotation of the right foot and knee joint around the right axis of rotation in the upward and forward direction is important.

The final action of shot-putting in the direction of the throw starts after rotation of the hips and shoulders stops. At the end of rotation of hips and shoulders the velocity of shot is 6.16 m.s^{-1}. After the right arm has taken part in the release action through extension of elbow and shoulders, the shot velocity increases by 6.78 m.s^{-1}. The distance over which the arm is activated throughout the shoulder and elbow extension phase is 0.98 m. At the moment of release the final velocity of the shot was 12.94 m.s^{-1}. A very efficient release action of the right arm may be ascertained, demonstrating itself in the parameters of the average angular velocity (875 °/sec.) and maximum angular velocity in elbow (1378 °/sec.).The extension action of the shoulder is also synchronised with extension of the elbow. The average angular velocity of the final shoulder is 452 °/sec. The maximum angular velocity of the final shoulder is 652 °/sec. It may be concluded that the velocity of shot release of our study subject is mostly related to his exceptional explosive power of the upper extremities and trunk, as his bench press result is 250 kg and dead lift result 155 kg. High level of release velocity is also connected with the technique of release action, with the following important factors: height of elbow, participation of finger flexor muscles in release action and blocking of left arm while preventing rotation at the moment of shot release.

CONCLUSION: Based on a biomechanical analysis of an elite shot-putter we have identified some of the key elements of the rotational shot-put technique that generate the competition result in this exceptionally complex track and field event. This study does not allow absolute generalisation of the data obtained, nevertheless, it may still provide us with very valuable information that is important for the track and field professional discipline and practice as well as sports science in the field of biomechanics. The following was ascertained based on the conducted kinematic analysis:

- One of the most important parameters of rotational shot-put technique is release velocity produced by the horizontal and vertical velocity vectors.
- Competition result is a consequence of optimal combination of release velocity, release angle and release height.
- Velocity of shot varies by movement phase, and is at its lowest in the flight phase. Therefore, the duration of this phase has to be as short as possible.
- The length of the path in the final acceleration phase depends on the lowest point of shot (1.35 m), maximum amortisation of the right knee and height of release point .
- Firm planting of the right foot in the middle of the throwing circle is the most important factor of efficient transformation of velocity from rotational movement to linear release velocity.
- The shot release velocity of the study subject (12.94 $m.s^{-1}$) is primarily connected to angular velocity in the elbow and the shoulder of the right arm.
- The rotational shot-put technique is an extremely complex movement, requiring a high level of motor control, biomotor abilities and an optimal constitution of the thrower.

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