3D KINEMATICS OF THE SWING ARM IN THE SECOND DOUBLE-SUPPORT PHASE OF ROTATIONAL SHOT PUT – ELITE VS SUB-ELITE ATHLETES

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Abstract:

The aim of this study was to identify the differences between the arithmetic means of angular displacement and angular velocity of the swing arm shoulder in the second double-support phase of sub-elite shot putters and the equivalent angular displacement and velocity of elite shot putters. The information resource was collected at international official competitions. The first sub-sample was comprised of 10 trials executed by sub-elite shot putters (length of the shot put over 16 m and less than 17.25 m) (group 1) and the second sub-sample was comprised of 10 trials executed by the elite shot putters (length of the shot put over 19 m and less than 20.44 m) (group 2). The collected video images were digitized using APAS. The difference between the sub-elite group and elite group was obtained in the angular displacement of the left shoulder. The crucial finding is that the swing of the left arm must be performed with an amplitude which allows the prestretching of structures which are active in the pushing phase or with an amplitude which does not allow any increase in the shot's movement radius.

Key words: *kinematics, shot put, swing arm, rotational technique*

Introduction

There are three parameters which determine the trajectory of a simple projectile, such as a shot: the release height, release angle and release velocity. The release height is a consequence of the athlete's length of the body (Lanka, 2000) and it is a prerequisite for a candidate's selection for shot-putting. The release angle depends on the release height and on the release velocity (Hubbard, de Mestre, & Scott, 2001; Linthorne, 2001). It is relatively constant for an individual athlete and cannot be changed to improve the result. The release velocity is by far the most important of all the release parameters in determining the distance achieved, because the distance is proportional to the square of the release velocity. Accordingly, the target of professional and scientific efforts would be to consider the possibilities for increasing the release velocity in shot-putting.

The actual release velocity in shot-putting is related to individual athletes' qualities, such as explosive power in particular and appropriate shot-putting technique. The release velocity is the outcome of the movement of the body segments of a shot putter – feet, shanks, thighs, trunk, upper arms, forearms, hands and head. An efficient movement pattern of shot-putting means the timely recruitment sequence of particular body segments into the movement. The coordination of muscle actions is often considered to be crucial for a successful performance of shot-putting. Therefore, the following question is justifiable: how should individual movements be coordinated (what and when) to exploit the maximal advantage of a shot putter's physical capabilities and for achieving the maximal speed of the shot?

Scientists discuss several principles and mechanisms that could enhance the release velocity of the shot. Although the role of movement variability in distance-dominated throws has not yet been fully explained, it would seem that prestretch (one of the universal principles of throwing; see Bartlett, 2000) can enhance the release velocity. It is well known that if a muscle shortens immediately after a stretch, force and power outputs increase (Cavagna, 1977; Komi, 1984). In throwing, active muscles are typically prestretched to enhance force output of movements (Čoh, et al, 2008; Bartlett, 2000; Lanka, 2000). Muscle and tendon elasticity, spinal reflexes and other mechanisms produce an important function in enhancing the motor output (Komi, 2002). Stretching of the muscles, tendons and ligaments of the shoulder girdle is important in shot-putting (Zatsiorsky, Lanka, & Shalmanov, 1981; Lanka, 2000). Specifically, it has been hypothesized that the swinging movement of the left arm backwards (in the right-handed athletes) immediately before the right arm extension induces the stretching of muscles, tendons and ligaments of the shoulder girdle (Bartonietz, 1990; Lanka, 2000). This mechanism could be important for the execution of a shot put and, therefore, could differen -tiate elite from sub-elite shot putters. However, to our best knowledge, no previous study examined the importance of this mechanism for the execution of shot puts.

The two important kinematic parameters that can describe an efficient swing movement of the free arm are angular displacement and angular velocity of the corresponding arm during the second double-support phase (second double-support phase of the rotational shot put lasts from the end of the second single support phase to the instant of releasing the shot; see Luthanen, Blomquist, & Vanttinen, 1997). Accordingly, the aim of this study was to compare the angular displacement and angular velocity of the swing arm shoulder in the first stage of the second double-support phase in sub-elite and elite shot putters. The determination of these differences could help determine the movement standard of this part of the rotational shot put technique. We hypothesized that there exist significant differences in angular displacement and angular velocity of the left shoulder in the first stage of the second double-support phase between the sub-elite and elite shot putters.

Methods

Subjects and experimental procedure

The sample consisted of 8 international-level shot putters who participated at four international official competitions. According to the purpose of this experiment, the shot putters and their corresponding trials were divided into two groups: the elite (4 shot putters) and the sub-elite (4 shot putters) ones. Their age, body mass, body height and the current best shot put are depicted in Table 1. For the elite group, we analysed altogether ten trials in which no shot put distance was under 19 metres. For the sub-elite group, we also analysed also 10 trials in which no shot put distance was longer than 17.25 metres. Such a division ensured relatively large performance differences between the samples. The dependent variables in this study were angular displacement (ADLS in degrees) and angular velocity (AVLS in degrees per second) of the left shoulder in the second double-support phase of the rotational shot put of the right-handed shot putters. Kinematic values of angular displacements and angular velocities of the upper arm at the shoulder were observed in those planes in which they have actually occurred at each and every put.

Data acquisition and processing

The performance has been recorded by two video cameras (mini DV, Panasonic NV-GS200), operating at 50 frames per second, positioned to provide 3D analyses (the angle between the optical axes of the two cameras was 90°). The analysed area of the circle was calibrated at a 1 m x 1 m x 2 m reference scaling frame. The reference scaling frame was placed in the throwing circle before the events and the positions were recorded for calibration purposes. 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 3D software (Ariel Dynamics Inc., San Diego, Ca.) was applied to determine the points on the digital video recordings and transform the 2 x 2D data into 3D. The coordinates of 18 points, defining the 14-segmental model of the human body were manually processed for each frame of the movement. The segments of the model represented parts of the body, linked with point-like joints. The

Table 1. Anthropological and performance characteristics of the sub-elite and elite shot putters

Athlete	Age (yrs)	Height (cm)	Body mass (kg)	Best score (cm)
E.E. (elite)	22	197	132	20.94
M.K. (elite)	26	192	123	20.61
M. V. (elite)	28	196	160	20.30
H. A. (elite)	26	188	125	19.49
K. R. (sub-elite)	24	200	135	19.09
D. M. (sub-elite)	41	197	130	18.24
J. Z. (sub-elite)	22	188	120	18.54
D. B. (sub-elite)	27	188	112	18.30
Average sub-elite	28	193.3	124.3	18.54
Average elite	25	193.3	135.0	20.33

transformation into the 3D space was made by the DLT (Direct Linear Transformation) method. The obtained 3D coordinates of the digitized body were then filtered using the Cubic Spline smoothing method. Descriptive statistics were calculated for both variables. The differences in angular displacement and angular velocity of the left shoulder in the second double-support phase of the rotational shot put technique between sub--elite and elite shot putters were tested using *t*-test for independent samples. A value of $p<.05$ was established *a priori* to determine the statistical significance.

Results

Figure 1 depicts a comparison of angular displacement (Figure 1a) and angular velocity (Figure 1b) of the left shoulder for two typical representatives of the elite and sub-elite shot putters. Note the marked differences in the previously mentioned parameters between the two shot putters.

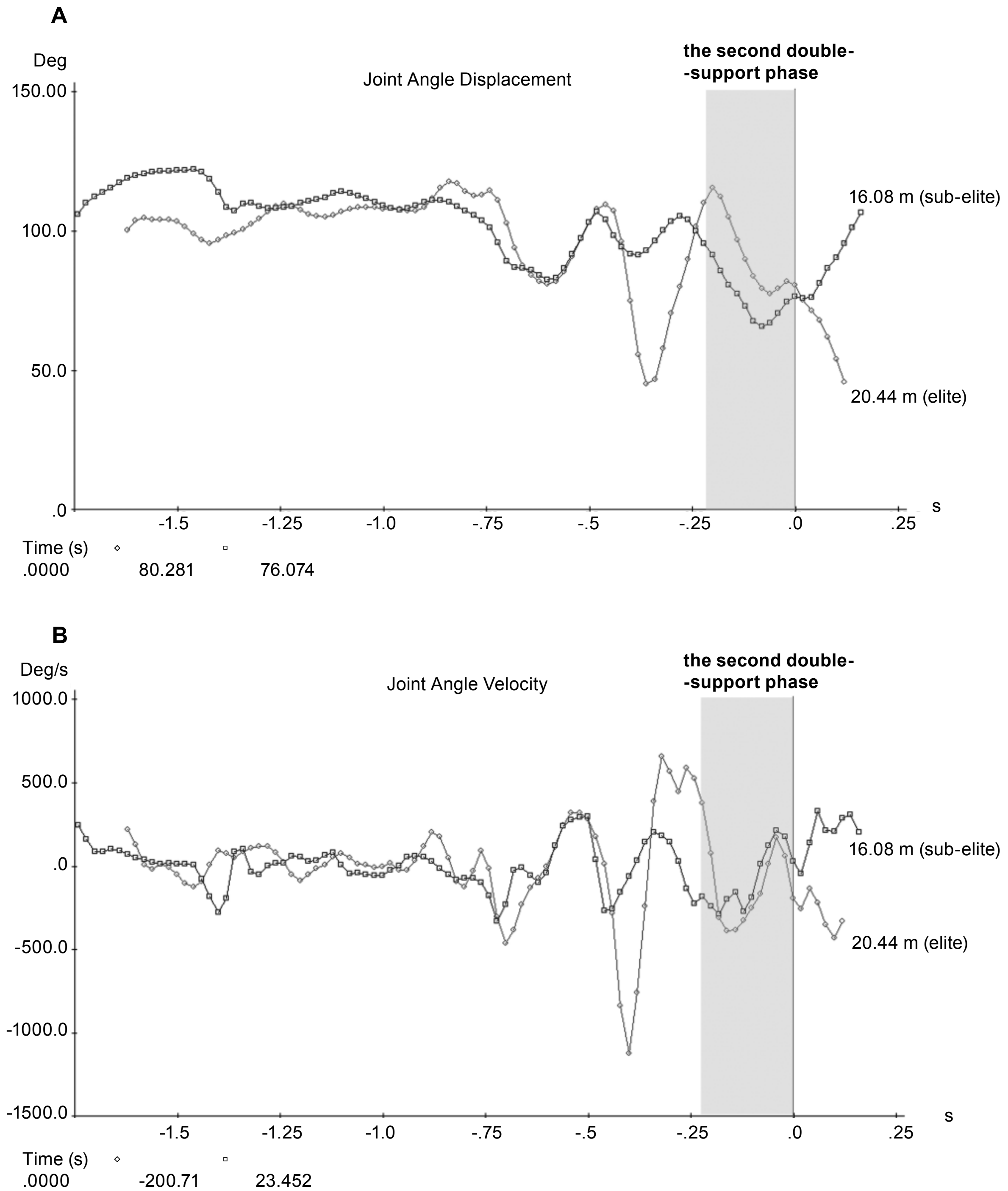

Figure 1. An example of the angular displacement (A) and angular velocity (B) of the left shoulder in the second double-support phase of the rotational shot put for one elite and one sub-elite shot putter.

Table 2. Descriptive statistics of angular displacement and angular velocity of the left shoulder in the second double-support phase of the rotational shot put technique for the sub-elite and elite shot putters and t-values

	M	R	SD	skew	kurt	CV%	t	p
Angular displacement sub-elite	26.89	38.62	10.62	-.46	.87	39.51 %	3.53	.002
Angular displacement elite	44.46*	32.13	11.63	.06	-1.47	26.15 %		
Angular velocity sub-elite	160.48	325.79	99.53	1.09	1.11	62.01 %	1.82	.086
Angular velocity elite	282.65	517.42	188.14	.73	-1.17	66.56 %		

* Denotes significant difference between the elite and sub-elite group ($p<.05$).
Legend: M – mean, R – range, SD – standard deviation, skew – skewness, kurt – kurtosis, CV% - variability, t – *t*-value)

The descriptive statistics of angular displacement and angular velocity of the left shoulder in the second double-support phase of the rotational shot put technique for both groups of shot putters are presented in Table 2.

It should be noted that the mean value of angular displacement of the left shoulder in the second double-support phase of the elite athletes is almost twice as high as the corresponding value observed in the sub-elite shot putters (*t*-value=3.53; p=.002). Moreover, the elite shot putters also produced markedly higher angular velocities of the left shoulder in the second double-support phase than the sub-elite shot putters. However, despite a large variability in this parameter, these differences were not statistically significant (*t*-value=1.82; p=.086).

Discussion

The main finding of this study was a significantly higher angular displacement of the left shoulder in the second double-support phase of the rotational shot put technique in the elite than in the sub-elite shot putters. These results suggest that the elite shot putters perform a greater angular displacement with the swing arm shoulder (forceful movement with the left arm) than the sub-elite shot putters, thus achieving a greater horizontal distance covered by the shot. This accentuated range of motion of the backward (non-dominant) arm swing immediately before the right (dominant) arm extension could enhance the release velocity of the shot during the delivery phase. Which mechanism or mechanical benefit lies in the background of the enhanced release velocity may be the topic of discussion. The universal principle of prestretch with reference to the mechanism of the stretch-shortening cycle can be the reason why the shot velocity increases during the final stage of throwing.

The swing of the left (non-dominant) arm immediately before the right (dominant) arm extension induces the stretching of the structures which are active in the consequent phase. This type of activity, known as the stretch-shortening cycle, or reversible muscle action, implies consecutive stretching and shortening of the muscles and tendons involved in the performance. The reversible muscle action comprises the initiation of the stretch reflex, the storage and recoil of elastic energy, and stretching the muscle to optimal length for forceful contraction (Bartlett, 2000; Lanka, 2000). The left arm swing allows the storage of elastic energy in the elastic elements of the agonist muscles which can be repaid during the action phase. In addition, it uses the length-tension relationship of the agonist muscles by increasing the muscle length to that at which maximum tension is developed. It is also believed that this action puts the agonist muscles on stretch, which promotes a greater rise in the spindle frequency causing an enhanced action (Bartlett, 2000). As a result of the previously mentioned functions, the shot velocity increases during the delivery phase.

Besides the prestretch, the motion of the swing arm is also connected with the moment of inertia of the shot. The trunk rotation during the final part of the push phase is an object of controversy among scientist and practitioners. This rotation causes the curving of the shot's trajectory in the horizontal plane. The shot can move in a wide loop (longer radius) or in a narrow loop (shorter radius), or the shot putter can turn around the shot. There is an opinion that a shot putter should perform the movement with the shot at the end of a short radius to maximize the rotational acceleration. In such a case, the left arm swing, as an antiflex obviously reduces the shot movement radius. The movement of the right arm should be initiated with a position that minimizes the moment of inertia (the principle which is valid in throws requiring distance, see Bartlett, 2000) of the shot which may enhance the speed at which the putting arm can be extended. On the contrary, increasing the shot movement radius increases the load of muscles and consequently a higher level of strength capabilities is necessary. Regardless of the mechanism of reversible muscle action or benefit which arises from the shot trajectory in the horizontal plane, the contribution of both mechanisms depends on a properly coordinated acceleration of the swing arm at the appropriate time.

Our results also showed that the elite shot putters had higher angular velocities of the left shoulder compared to the sub-elite shot putters, but these differences were not statistically significant. In this connection, the new question is why the velocity of the swinging arm is not different although a shot putting is speed-dependant, and so are all throws whose goal is throwing for distance. Although this signifies that the sub-elite and elite athletes were not different as regards this criterion, this does not mean that a forceful accelerated movement of the left arm backwards immediately before the right arm extension is not crucial. The obtained results do not point to the fact that the swing of the left arm need not be fast. They indicate that it must be performed with an amplitude which allows for the prestretch of structures that are active in the next phase or with an amplitude which does not allow for the increase in the shot's movement radius. Whereas the second double-support phase lasts less than two tenths of a second, the prestretch must occur immediately before the activation of the right arm and its efficacy depends on a properly coordinated acceleration of the swing arm at the appropriate time. The coordination of intermuscular actions is considered to be crucial for the successful execution of the final phase of a shot put.

Conclusions and recommendations for coaches

The difference between the sub-elite group and the elite group was obtained in the angular displacement of the left shoulder. No statistically significant difference was found between the groups for the variable of the angular velocity of the left shoulder. This makes it possible to conclude that regardless of the mechanism of reversible muscle action or benefit which arises from the shot trajectory in the horizontal plane, the contribution of the swing arm depends on a properly coordinated acceleration of the left upper arm at the appropriate time. The crucial finding is that the swing of the left arm must be performed at a proper time and with an adequate amplitude. Therefore, coaches are advised to pay particular attention to the correct execution of the left arm swing during the final phase of a shot put. However, this research could not explain the mechanism responsible for performance improvement as a result of a coordinated arm swing of the left (non-dominant, non-putting) arm. Future studies are needed to explain whether muscle tendon prestretch or the shot's movement radius are the likely mechanisms behind the observed shot put performance enhancement as a result of the left arm swing.

References

Bartlett, R. (2000). Principles of throwing. In V. M.Zatsiorsky (Ed.), *Biomechanics in sport* (pp. 365-380). Oxford: Blackwell Science.

Bartonietz, K. (1990). Drehtechnik kontra Angleittechnik? Erfrahungen, erkenntnisse und hypothesen zur Kugelstoβ-Drehtecnik, veranshaulicht en einem 22-m stoβ von Randy Barnes. *Lehre der Leichathletik*, *29*, 15-18.

Cavagna, G.A. (1977). Storage and utilization of elastic energy in skeletal muscle. *Exercise and Sport Sciences Reviews*, *5*, 89-129.

Čoh, M., Stuhec, S., Smajlović, N., & Supej, M. (2008). Comparative 3-D analysis of the rotational shot-put technique. In M. Čoh (Ed.), *Biomechanical diagnostic methods in athletic training* (pp. 27-34). Ljubljana: Faculty of sport, Institute of Kinesiology.

Hubbard, M., de Mestre, N.J., & Scott, J. (2001). Dependence of release variables in the shot put. *Journal of Biomechanics*, *34*, 449-456.

Komi, P.V. (1984). Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exercise and Sport Sciences Reviews*, *12*, 81-121.

Komi, P.V. (2002). Stretch-shortening cycle. In P.V. Komi (Ed.), *Strength and power in sport* (pp. 184-202). Oxford: Blackwell Science.

Lanka, J. (2000). Shot putting. In V.M. Zatsiorsky (Ed.), *Biomechanics in sport* (pp. 435-457). Oxford: Blackwell Science.

Linthorne, N.P. (2001). Optimum release angle in the shot put. *Journal of Sports Sciences*, *19*, 359-372.

Luthanen, P., Blomqvist, M., & Vanttinen, T. (1997). A comparsion of two elite shot putters using the rotational shot put technique. *New Studies in Athletics*, *12*, 25-33.

Zatsiorsky, V.M., Lanka, J., & Shalmanov, A.A. (1981). Biomechanical analysis of shot putting technique. *Exercise and Sport Sciences Reviews*, *9*, 353-389.

3D KINEMATIČKA ANALIZA ZAMAŠNE RUKE U DRUGOJ DVOPOTPORNOJ FAZI BACANJA KUGLE ROTACIJSKOM TEHNIKOM – RAZLIKE IZMEĐU KVALITETNIH I VRHUNSKIH BACAČA

Cilj ovog istraživanja bio je utvrditi razlike između aritmetičkih sredina kutnog pomaka i kutne brzine u zglobu ramena zamašne ruke u drugoj dvopotpornoj fazi kvalitetnih bacača i kutnog pomaka i kutne brzine u istom zglobu vrhunskih bacača kugle. Uzorak je prikupljen na službenim međunarodnim natjecanjima. Prvi poduzorak bacanja kvalitetnih bacača (duljina hica je bila veća od 16 m, a manja od 17,25 m) sastojao se od 10 ispravnih hitaca (skupina 1), a i drugi poduzorak bacanja vrhunskih bacača (duljina hica je bila veća od 19 m, a manja od 20,44 m) sastojao se također od 10 ispravnih hitaca (skupina 2). Prikupljeni uzorak izvedenih bacanja digitaliziran je korištenjem APAS-a. Razlika između skupina kvalitetnih i vrhunskih bacača utvrđena je u kutnom pomaku u ramenu zamašne ruke. Glavni nalaz ovog istraživanja jest podatak da zamah zamašnom rukom mora biti izveden amplitudom koja će osigurati predistezanje struktura koje su aktivne u fazi potiskivanja kugle ili amplitudom koja neće dopustiti povećanje radijusa kojim se kugla giba u završnoj fazi bacanja.

Ključne riječi: *kinematika, bacanje kugle, zamašna ruka, rotacijska tehnika*

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