

INFLUENCE OF ANTHROPOMETRIC AND KINEMATIC PARAMETERS ON RESULT SUCCESSFULNESS OF SHOT PUT FINALISTS (WC BERLIN 2009-DAEGU 2011)

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How to cite this article: Pavlović, R. & Vrcić, M. (March, 2019). Influence of anthropometric and kinematic parameters on result successfulness of shot put finalists (WCh Berlin 2009-Daegu 2011). Journal of Physical Education Research, Volume 6, Issue I, 29-37.

Received: December 08, 2018

Accepted: March 02, 2019

ABSTRACT

*Anthropometric characteristics and biomechanical parameters alongside with motor and specific-motor skills in great measures define results in athletic throwing disciplines. Their influence is different and often it is an indicator of obtaining good results. Current research is conducted with the finalists of World Championship (Berlin, 2009; Daegu, 2011) with the aim to determine the influence of anthropometric and kinematic parameters of the throw (release velocity, release height, release angle) on result successfulness in shot put. A total of 32 competitors were included in the research, out of which 16 was male (height, $192,13 \pm 7,61$ cm; weight $133,44 \pm 14,85$ kg) and 16 female finalists (height $182,94 \pm 6,31$ cm; weight $95,81 \pm 14,28$ kg). Obtained results were processed by multiple regression analysis which confirmed statistically significant influence of predictors on the result of male shot put finalists ($R=0,793^{**}$, $R^2=0,629$) and female finalists ($R=0,806^{**}$; $R^2=0,650$). The obtained results of regression analysis confirmed that the speed of the throw-out (V_o) was a leading parameter in the successfulness of the finalists' result [$Beta(f)=0,691$; $Beta(m)=0,528$] and inverse relation with the angle of the throw-out, which can be confirmed by previous research on this subject. It is interesting that the angle of the throw-out in female shot putters was not defined as a factor of the impact on regression function, while the height of the throw-out recorded slight inversion in comparison to throw-out angle and the speed as a consequence of force of gravity.*

Keywords: Elite shot putters, shot put, throw-out parameters, anthropometric characteristics

1. INTRODUCTION

Shot put, discus throw and javelin throw belong to the acyclic-cyclic track and field disciplines. Two putting techniques are in current use by shot put competitors: the glide and the spin. Today, more than 60% of the male and 40% female shot-putters use spin techniques. The spin involves rotating like a discus thrower and using rotational momentum for power. The glide technique involves the putter facing backwards, rotating 180 degrees across the circle, and then tossing the shot. With this technique, a right-hand thrower transfers the weight from right to the left leg and performs a rotation of the whole body (Lanka, 2000). As it can be seen, in the entire kinematic chain participating in the shot put, lower limbs play a significant role. For this reason, in the studies of the biomechanics of shot put, among other things, the values of ground reaction force components exerted against the right and left foot during delivery were highlighted (Bowerman, Freeman, & vern Gambetta, 1998; Peng, Peng, & Huang, 2008). The shot put is a field event in athletics and each of the events has a specific set of restrictions including (a) the characteristics of the implement used (size weight and aerodynamic qualities), (b) space limitations and (c) technique requirements which influence the sequence of events and make them unique (Pavlović, 2016; Kapur & Devi-Khomdramm, 2017). The goal in the throwing events is to maximize the measured distance covered by the implement and this distance is determined by a number of parameters for example height, velocity, angle of release (Linthorn, 2001; Lenz & Rappl, 2010; Pavlović, 2016), aerodynamic qualities and environmental factors (Idrizović, 2010; Stanković & Raković, 2010; Mihajlović, 2010), exploitation of the escape space when the equipment is thrown out and temporary foot position (Bowerman et al., 1998; Smajlović, 2010). The release height is a consequence of the athlete's length of the body, length of arm; body mass (Bowerman et al. 1998; Lanka, 2000, Pavlović, 2016) and it is a prerequisite for a candidate's selection for shot-putting (Čoh, 2002). The release angle depends on the release height and on the release velocity (Hubbard, de Mestre, & Scott, 2001; Linthorne, 2001). The angle of the release is smaller, the higher the height and the speed of the throw (Čoh, 2002). 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 (Mihajlović, 2010; Stefanović & Bošnjak, 2011).

The actual release velocity in shot-putting is related to individual athletes' qualities, such as explosive power in particular and appropriate shot-putting technique (Harasin, Milanović, & Čoh, 2010). Good performance in mentioned track and field competitions are mainly determined by the athlete's technique than the tactics. Shot-put is an explosive power event developed to maximum efficiency through the proper sequence of events and directed at the correct angle is a secret to a record put of the shot. Especially the spin shot put technique is an extremely complex movement, which requires a high level of motor control, bio motor abilities and an optimal constitution of the thrower (Čoh & Jošt, 2005). Power is a function of force times velocity. The sequence of movements with mechanical principles can be divided into four phase's i.e. the hop, the body rotation, the arm thrust and weight snap. The proper and correct sequence of involvement of phases and muscles, joints helps one to attain the maximum possible distance (Kapur & Devi-Khomdramm, 2017). Much research has been performed on the shot put, and several of these studies have examined the theory and practice of determining optimal release conditions, such as release speed, release angle and release height (McWatt, 1982; Maheras, 1995; Hubbard et al., 2001; Linthorne, 2001). Although these parameters directly determine the projected distance of the throw, they do not give any indication of the events leading up to the release. Consequently, they offer limited information to coaches seeking to improve the aspects of technique that will result in the best release parameters (Young & Li, 2005). Some other studies have been descriptive and these have ranged from quantitative (Knudson, 1989; Bartonietz, 1996; McCoy, 1990; Stepánek, 1990; Liu, Yun, Liu, & Wang, 2000) to completely qualitative (Wilt, 1982; Grigalka & Papanov, 1984). Although these studies do provide information about the kinematics of the performance, they too offered limited evidence as to which parameters were most influential on the performance. Also, the relative importance of each critical factor will vary for each athlete depending on such things as gender, anthropometry, strength parameters, throwing technique used (glide or spin), and individual stylistic elements (Young & Li, 2005).

In their research Čoh and Jošt (2005) define some of the most important kinematic parameters of the rotational shot put technique. They used a 15-segment model of the thrower with 23 reference points defined. The results showed that the top result of the throw depends on release velocity, the optimal angle of release, the relation between the rotational motion and acceleration of the final shot, and the angular velocity of the elbow and shoulder joints of the used hand. The key phases which ensure correct rhythm and generate high release velocity of the shot are the following: flight phase, second single support phase and second double support phase. The authors Čoh, Stuhec, Smajlović and Supej (2008) investigated the rotational model of the two techniques of elite shot putters with different anthropometric measures. Differences were found for: release velocity, release height, the maximum angular velocity in the elbow joint of the throwing hand, the trajectory of the thrower and the shot, torsional rotation in the shoulder joint compared to the axis of the hip joint, maximum force focused on the ball, the kinetic energy independent of the sphere. Critical factors measured in this study included the speed of turning the right foot and the maximum force developed, the angle and height of release and release velocity during the last phase. These factors are examined in connection with each athlete's throwing distance. A greater angle of release causes a higher shot flight from the ground, but lower speed. During the flight phase the shot acts as a projectile in free flight and its path can be calculated by using data on the conditions of release. Linthorne (2001) aims to assess the accuracy of the method of calculating the angle of ejection for throwing shots. With this method the optimal angle of release, which produces the longest distance, is calculated by combining the equation for the range of missiles during free flight with a connection among the release velocity, release length and angle of release. A crucial finding of the study of Harasin et al. (2010) is that the swing of the left hand must be performed with an amplitude that allows the pre stretching of structures that are active in the pushing phase or with an amplitude that does not allow an increase in the shot movement radius. Release parameters are very important for successful performance and are mutually dependent. When the throw is made above the horizontal plane, the length of the throw depends on the height, angle and velocity of the release (Wang & Chen, 2002). When athletes throw with a high angle of release, the shot is thrown to greater heights, but with lower velocity. Simple models of throwing were developed to explain the relationship between the release velocity, height and angle related to the anthropometric measures and motor abilities of athletes (Linthorne, 2001). The most important observation of the study Young and Li (2005) was the identification of critical parameters for successful performance by elite female shot putters. This study is the first to examine critical parameters for success in elite women shot putters and indicates specific parameters that are important for achieving the highest standard in the event. The results of this study suggest that, among elite shot putters, bigger rear knee flexion at rear foot touch-down and release, increased release speed, a more neutral shoulder-hip angle at release and a larger Horizontal release distance were the best predictors of measured distance. Correlation analysis of study Young and Li (2005) indicated that measured distance was positively correlated with release speed ($r = 0.97$, $p < 0.0003$) and shoulder-hip separation ($r = 0.72$, $p < 0.06$) and negatively correlated with release angle ($r = -0.74$, $p < 0.056$), rear knee angle at rear foot touchdown ($r = -0.93$, $p < 0.003$) and rear knee angle at release ($r = -0.76$, $p < 0.047$). Greater knee flexion angle at both rear foot touch-down and release along with a neutral shoulder-hip angle at release were Identified as the most critical parameters for success among

this sample of elite women shot putters. The research Hubbard, de Mestre and Scott, 2001 between two throwers Multivariate regression analyses determined that achievable release speed decreases with increasing release angle at about 1.7 (m/s)/rad and decreases with increasing release height at about 0.8 (m/s)/m, with only small differences in sensitivities between the throwers. Horizontal release distance also decreases with increasing release angle at about 1.7 m/rad and increases with increasing release height at about 1.3 m/m, again with only small differences between the two throwers.

The main of the research is to define and determine the influence of anthropometric and kinematic parameters on the success of the Shot Put of male and female finalists of the World Championship in Berlin, 2009 and Daegu, 2011.

2. METHODS AND MATERIALS

2.1 Participants

The population defined in the research has included top athletes in the Shot Put World Championship in Berlin, 2009. and Daegu, 2011. The sample included a total of 16 male finalists (Height=192,13±7,61cm; Weight=133,44±14,85kg) and 16 female finalists (Height=182,94±6,31cm; Weight=95,81±14,28kg), who participated in the Shot Put Final.

2.2 Variables of the Study

The variables of the study were - Release Velocity (m/s), Release Angle (°), Release Height (m), Body Height (cm), and Body Weight (kg).

2.3 Statistical Analysis

Data obtained in the survey were analyzed by standard descriptive methods, and the influence of anthropometric and kinematic parameters on the resulting ball throwing success was calculated using Regression analysis. Statistical analysis was done using the statistical program Statistica 8.0

3. RESULTS

Table 1: Biomechanical parameters of male and female finalists - WCh Berlin, 2009 (Mendoza et al. 2009)

Male finalists	Result (m)	Relase Velocity (m/s)	Relase Angle (°)	Relase Height (m)	Body Height (cm)	Body Weight (kg)
Christian Cantwell R	22.03	14	37.8	2.29	196	150
Tomaš Majewski L	21.91	13.8	39.3	2.43	204	140
Ralf Bartles L	21.37	14	33.6	2.12	186	125
Reess Hoffa R	21.28	14	34.4	2.06	182	133
Adam Nelson R	21.11	14.1	32.9	2.05	183	115
Pavel Lizhin R	20.98	13.6	39.2	2.22	189	110
Andrey Miknevich L	20.74	13.4	37.7	2.43	202	127
Miroslav Vodovnik R	20.50	13.7	33.1	2.25	197	160
Mean	21.24	13.83	36.00	2.23	192.38	132.50
Female finalists	Result (m)	Relase velocity (m/s)	Relase angle (°)	Relase height (m)	Body height (cm)	Body weight (kg)
Valerie Adams Vili	20.44	13.6	37.5	2.16	196	120
Natallia Mikhnevich	20.20	13.5	39.6	1.93	180	85
Nadezeya Ostapchuk	19.89	13.4	35.7	1.99	180	95
Misleydis Gonzalez	19.66	13.2	37.3	2.08	179	75
Lijiao Gong	19.66	13.3	36.0	2.03	180	80
Anna Omarova	18.96	13.0	37.2	2.07	178	107
Nadine Kleinert	18.76	13.0	36.8	1.91	190	90
Meiju Li	18.74	13.2	34.2	1.84	182	81
Mean	19.54	13.30	36.80	2.10	183.13	91.63

By inspection of Table 1 we can see the ratio between the throw-out speed and throw-out angle of male and female finalists. Average throw-out speed of male finalists on World Championship in Berlin in 2009 was 13,80 m/s, with the average angle of 36,80° and throw-out height of 2,23 m (elite average 220-235 cm). The biggest throw-out speed was achieved by fifth-ranked A. Nelson (14,10 m/s), the best throw-out angle was achieved by second-ranked T. Majewski (39,30°), and throw-out height (2,43 m) Majewski and Miknevich. In comparison to male, female finalists achieved slightly smaller average throw-out speed (13,30 m/s), bigger

throw-out angle (36,90°) and smaller throw-out height of 2,10m. The biggest throw-out speed was achieved by first-ranked V.Vili (13,6 m/s) which is 0,5 m/s weaker than the best male result. The biggest throw-out angle was 39,60° and was recorded in second-ranked N. Miknevich, which is 0,3° more than the result ofTomaš Majewski. In the third parameter (throw-out height the biggest difference can be observed, which is logical, if we compare body height of male and female shot putters. First-ranked V.Vili (Body Height 196 cm) threw shot put from the height of 2,16 m which is 27 cm less than Majewski Body Height 204 cm) and Miknevich (Body Height 202 cm).

Table 2: Biomechanical parameters of male and female finalists – WCh Daegu, 2011. (Oh, Shin, Choi, 2011)

Male finalists	Result (m)	Relase velocity (m/s)	Relase angle (°)	Relase height (m)	Body height (cm)	Body Weight (kg)
David Storl (L)	21.78	13.96	37.20	2.27	199	122
Dilan Armstrong (R)	21.64	13.03	37.47	2.11	193	155
Andrey Miknevich (L)	21.40	13.37	35.70	2.20	202	127
Christian Cantwell (R)	21.36	12.94	35.96	2.06	196	150
Resse Hoffa (R)	20.99	13.51	31.16	2.02	182	133
Marco Fortes (R)	20.83	13.26	31.87	2.09	189	139
Ryan Whiting (R)	20.75	12.75	37.31	1.91	191	134
Adam Nelson (R)	20.29	13.14	30.79	2.10	183	115
Mean	21.13	13.25	34.68	2.10	191.88	134.38
Female finalists	Result (m)	Relase velocity (m/s)	Relase angle (°)	Relase height (m)	Body height (cm)	Body weight (kg)
Adams. V. (L)	21.24	13.75	33.49	2.21	196	120
Ostapchuk. N. (L)	20.05	13.14	39.18	2.09	180	95
Camarena-W.J. (Pro)	20.02	13.26	33.95	1.95	178	113
Gong. L. (L)	19.97	13.06	35.17	1.90	180	80
Kolodko. Y. (L)	19.78	13.04	37.77	2.07	182	92
Li. L. (L)	19.71	12.91	35.68	2.03	181	110
Avdeeva. A. (L)	19.54	13.20	35.13	1.94	175	100
Kleinert. N. (L)	19.26	12.70	34.45	1.93	190	90
Mean	19.94	13.13	35.60	2.01	182.76	100

Table 2 identified almost identical parameter values, or inverse relation between speed, angle and throw-out height of male and female finalists on WC in Daegu in 2011. Average throw-out speed of male finalists on World Championship in Daegu in 2011 was 13,25 m/s, with average angle of 34,68° and throw-out height of 2,10 m (which is under elite average). The biggest throw-out speed (13,96 m/s) and throw-out height (2,27 m) was achieved by first-ranked D.Storl, and throw-out angle was achieved by D.Armstrong 37,47°. In comparison to male, female finalists achieved slightly smaller average throw-out speed of 13,13 m/s, bigger throw-out angle of 35,60° and smaller throw-out height of 2,01m. The biggest throw-out speed was achieved by first-ranked V.Vili (13,75 m/s) which is for 0,21 m/s weaker than the best male finalist with throw-out speed of 2,21 m. The biggest throw-out angle of 39,18° was recorded in second-ranked N. Ostapchuk. In order to obtain answers to the defined aim of the research, or in which measure anthropometric parameters (body height, body weight) as well as kinematic throw-out parameters (speed, angle and height) influenced achieved results of the finalists of World championships, multiple regression analysis was used and relevant statistical parameters were calculated.

Table 3: Regression summary for dependent variable ‘shot put male’

	BETA	Partial Cor.	B	St.Err of B	t (26)	p-level	Pearson corelation p <0.05
Intercpt			4.75	3.384	1.403	.172	
Relase velocity (m/s)	0.691	0.654	0.811	0.187	4.331	0.000**	0.56
Relase angle (°)	0.573	0.574	0.104	0.029	3.494	0.002**	0.40
Relase height (m)	-0.526	-0.393	-0.027	0.008	-2.180	0.039*	0.32
Body height (cm)	0.383	0.273	0.025	0.017	1.441	0.162	0.39
Body weight (kg)	0.236	0.312	0.013	0.005	1.687	0.103	0.24
Analysis of Variance	Sums of Squares	Df	Mean Squares	F	p-level		
Regress.	4.759	5	0.952	8.772	0.000		
Residual	2.821	26	0.109				
Total	7.580						

R= 0,793 R²=0,629 Adjusted R²=0,556F(5,26)=8,771 p<0,000

Regression analysis of result successfulness of shot put male finalists in Berlin and Daegu (Table 3) indicates to statistically significant correlation of the overall system of independent parameters with result

successfulness of shot put, where multiple correlation coefficient is significantly high ($R=0,793$). As determination coefficient is ($R^2=0,629$), that shows that joint variability between predictor system and criteria variables is conditioned by applied predictor system with around 63%, while the rest 37% is conditioned by other factors which are not included in this research, primarily motor, specifically motor and technical qualities of shot putters, by influence of exogenous factors, etc. By analysis of the values of regression coefficients (BETA) in the system of predictor variables, what can be evident is specific contribution of all defined variables, where not all of them achieved statistical significance of the influence. In the first place, as a leading predictor is a variable of throw-out speed (0,691; $p<0,01^{**}$), then throw-out angle (0,573; $p<0,01^{**}$) and throw-out height (-0,526; $p<0,05^{*}$). Anthropometric parameters (height and weight) achieved influence but not statistical significance as well ($p>0,162$; $p>,103$) on the throw-out result. Significant direct influence was confirmed in partial correlations of predictor set on criteria. Negative inverse relation was determined only in throw-out height, so it can be concluded that throw-out height of competitors was not a key factor in result successfulness of shot put in comparison to the speed and angle of throw-out as well as body height and weight of shot putters. By analysis of the biggest individual contribution (t) in the explanation of criteria of every variable the order is the same as in regression coefficients and partial correlation values. The biggest individual direct influence was achieved by throw-out speed ($t=4,331$), throw-out angle ($t= 3,494$) and throw-out height ($t= -2,180$), and somewhat weaker but positive influence was seen in body weight ($t=1,687$) and body height ($t=1,441$). Based on variant analysis we conclude that regression variability is statistically bigger than residual variability on both levels which indicates and guarantees statistical significance of regression connection. Thus, the information which was provided by slightly smaller corrected coefficient of determination was confirmed (adjusted=0,556). Correlation Pearson matrix correlation confirmed values and relations of regression analysis, where the biggest relation with the result of shot put was recorded in throw-out speed (0,56), throw-out angle (0,40), body height (0,39) and throw-out height (0,32). As the weakest predictor in regression function of males is body weight of shot putter.

Table 4: Regression summary for dependent variable 'shot put female'

	BETA	Partial cor.	B	St. Err. of B	t (26)	p-level	Pearson correlation p <0.05
Intercept			-.603	4.284	-.141	.889	
Release velocity (m/s)	0.528	0.617	1.257	0.314	4.003	0.000**	0.72
Release angle (°)	-0.081	-0.118	-0.028	0.047	-0.608	0.549	0.00
Release height (m)	0.385	0.413	0.024	0.010	2.311	0.029*	0.64
Body height (cm)	-0.020	-0.029	-0.002	0.013	-0.146	0.885	0.34
Body weight (kg)	0.071	0.089	0.003	0.007	0.456	0.652	0.47
Analysis of Variance	Sums of Squares	df	Mean Squares	F	Plevel		
Regress.	7.873	5	1.575	9.658	.0000		
Residual	4.239	26	0.163				
Total	12.112						

$R=0,806$ $R^2=0,650$ Adjusted $R^2=0,582$ $F(5,26)=9,657$ $p<,000$

In Table 4 regression analysis of result successfulness of female shot put finalists is represented. Acquired regression function, also indicates to statistically significant relation between two analysed systems which is confirmed by significantly high multiple correlation coefficient ($R=0,806$) with significant determination coefficient ($R^2=0,650$), from which we can conclude that joint variability between predictor system and criteria variable conditioned by applied predictor system with 65%, while the remaining 35% was conditioned by other factors which were not included in this research, moreover motor, specific motor and technical qualities of shot putters, influence of exogenous factors, etc. By analysing the values of regression coefficient (BETA) in the system of predictor variables we can record slightly different individual contribution of all defined variables in relation to male contestants. Out of the overall number of variables, only two recorded statistically significant influence on the result of shot put. In the first place, as a leading predictor and carrier of regression function is a variable of throw-out speed (0,528; $p<0,01^{**}$), and throw-out height (-0,385; $p<0,05^{*}$). Throw-out angle (-0,081; $p>0,549$), body weight (0,071; $p>0,652$) and shot putter height (-0,020; $p>0,885$) did not have significant influence on shot put result. In relation to male shot putters, throw-out speed of the shot put in females is a dominant factor for result successfulness of the defined parameters. By analysing the biggest individual contribution (t) in the description of criteria of all variables, the order is the same as in regression coefficients and values of partial correlation. The biggest individual direct influence was achieved by throw-out speed ($t=4,003$) and throw-out height ($t= 2,311$). Based on variance analysis we can conclude that regression variability is statistically and significantly bigger than residual variability on both levels which indicates and guarantees statistical significance of regression relation. By that the information which was given by slightly smaller corrected determination coefficient was confirmed

(adjusted=0,582). Pearson matrix correlation confirmed values and relations of regression analysis, where the biggest correlation with throw-out result was recorded by throw-out speed (0,72), throw-out height (0,64) and body weight (0,47). The weakest predictor in regression function of females is body height and throw-out angle.

4. DISCUSSION

Shot put belongs to acyclic movements of translator movement type with the aim of giving maximum speed to the object which is thrown. Throwing technique is determined by morphological characteristics (height, weight, arm length), and the direction of ball shot put movement on ballistic curve, from the moment of leaving athlete's hand until the contact with the ground depends on the starting throw-out speed, throw-out angle and throw-out height (Tončev, 2001). These parameters were actually manifestation of trajectory length on which the athlete had an influence of the shot put from the starting position of the shot putter until its leaving of the shot putters hand (Stepanek, 1989; Hubbard et. al 2001). Optimal angle of 45° is often mentioned as mathematical optimal angle, and which in practice is very hard to obtain. Overall length of the throw-out trajectory (active muscle impact) is between 3,2-3,9m, with shot put speed of 2,1m/s-2,3m/s in the first phase to 12,89m/s during throw-out with the duration of 0,16-0,20sec and force of 70-80kg (Čoh,2002). According to Pavlović (2016) throw-out speed goes over 14m/s, and depends on the length of the trajectory of active muscle activity of shot putter when from low position (shot put height 90-100cm) ends on throw-out height 220-230 cm in top shot putters (Stefanović & Bošnjak, 2011).

The achieved result of the throw depends on morphological characteristics, motor abilities, and throwing technique (Čoh & Jošt, 2005). In Linthorne's opinion (2001) the throwing technique requires great throwing explosive strength and the ability to perform the elements in the precise moment and in limited space. The goal of the athlete is to throw the shot away as far as possible, but according to the rules and regulations of the competition. Rotational (spin) and the Slide (O'Brien) throwing techniques are considered equal, but it was noticed that beginners and female athletes often use the slide technique, while men use the rotational technique of throwing more often (Young, 2009). Basic aim of this study was to determine the influence of anthropometric and kinematic parameters on the result successfulness of throw-out in male and female finalists on WC in Berlin, 2009 and Daegu 2011. Based on obtained results of multiple regression analysis it can be concluded that defined anthropometric and kinematic parameters obtained significant regression function with high multiple correlation, almost identical numeric values (around 895) and statistical significance ($p<0,05$; $p<0,01$). Determination coefficients differ slightly, in women numeric value was ($R^2=65\%$) in relation to male shot putters ($R^2=63\%$). The remaining 35-37% in both subsamples is attributed to motor abilities which are not taken as a subject of the research (power, speed, coordination, flexibility, balance), specifically-motor abilities (explosive leg power, arm power, individual movement seed, arms flexibility, body, et.) surface reaction force (Peng et al. 2008), of course performance technique and correct participation of individual segments of the body in the technique conduction (Young i Li, 2005). However, it is evident that this research confirmed findings of previous research of some authors which claim that throw-out result depends on the throw-out parameters (Bowerman et al. 1998; Čoh, 2002; Jovović, 2006, Idrizović, 2010, Mihajlović, 2010) and anthropometric characteristics and motor skills (Stanković & Raković, 2010).

According to Blaskiewicz et al., (2016) the release parameters are what actually determine the measured distance of the throw. In theory, one could easily use the projectile motion equation to find optimal release parameters that would result in a given distance. Release velocity is undoubtedly the most important factor in determining the distance of a throw. Release velocities in excess of 13 m/s are necessary for elite level throws. As such, all attempts should be made to maximize release velocity. This recommendation however must be made with the caution and advice that increasing either the athlete or the implement velocity at one phase of the throw will not necessarily increase velocity at release. Increasing velocity prematurely can result in instability, technical problems, decreased muscle loading, or inefficient sequencing of muscle contractions. Obtained results confirm the statements about throw-out speed as a dominant factor for the shot put throw-out result. Starting throw-out speed (V_0) is the most significant factor for the ending range of the shot put (i.e. during the increase of the V_0 for 10% the result of 3 meters can be achieved). World top shot putters achieve throw-out speed of 12,5 to 14,5m/s and achieve result of 19-23m (Pavlović 2016). In this research the average speed of throw-out of male finalists was 13,54m/s, and in female it was 13,21m/s which is recommended for elite shot putters. In regression function value (V_0 m/s) the coefficient was almost 0,70 (Beta=0,691). By inspection into individual results it is evident that some male and female shot putters had throw-out speed of around 14m/s and more than 14m/s (Cantwell, Majewski, Bartles, Hoffa, Nelson) which is also a good quality indicator. Better results were recorded in 50% male finalists in Berlin in comparison to Daegu, where there are observable slightly smaller values in both subsamples. Female athletes has smaller

throw-out speed ($V_o=13,26\text{m/s}$) but in comparison with the angle and height, the speed was dominant as a predictor in achieving a good result ($\text{Beta}=0,528$).

Generally, it is shown that the throw-out speed is a dominant factor in result successfulness of throw-out of shot put and therefore the main carrier of regression function. According to Opavski (1997) throw-out speed can be increased if rational contraction of three-headed muscle of the lower arm is used. During pushing movement of the shot put a better result is achieved when upper arm is moving on the side, with simultaneous revulsion in shoulder ankle and stretching in the elbow, more than it is when upper arm is moving forward with no significant revulsion. That is explained by the fact that the three-headed muscle of the upper arm participate in the stretching of the elbow and approximation in shoulder ankle. Under the condition that elbow bending was conducted and that muscles which approximate the upper arm are previously attached, it allows a better position for generating stretching forces in the elbow. Therefore, with simultaneous revulsion in shoulder ankle and stretching in the elbow a better result can be achieved in shot put, more than when the upper arm moves forward with no significant revulsion. This is good to know and apply while performing shot put technique. Within the parameters of the throw-out inverse relation has been determined between throw-out speed and throw-out angle. Average and individual results of the study confirmed previous research which confirm inverse relation between throw-out speed and angle, or that by increasing the throw-out force, throw-out angle decreases (Hubbard, et al. 2001; Linthorne, 2001; Čoh, 2002; Jovović, 2006; Smajlović, 2010; Stanković & Raković, 2010; Stefanović & Bošnjak, 2011; Pavlović, 2016).

The primary importance of release angle is its effect on the release velocity. As long as the release angle is within a range permitting elite level throws, it should be optimized to enable greater release velocities. In so doing, the measured distance will be greater. The research has indicated that for humans the release parameters are optimized when the angle of release is between 31° and 36° . This is considerably lower than the mathematically "optimal" range of 40° to 43° for elite throwers determined by using the projectile motion equation. While it is impractical for coaches and athletes to aim for exact release angles, it is important to know that lower release angles are actually advantageous as long as they still permit elite level throws; and that the mathematically optimal release angles will more than likely result in decreased throwing distances Blaskiewicz, et al. 2016. According to Lenz and Rappl. (2010), the simplest model - mostly used in textbooks - gives a value of 45° , while measurements of top athletes cluster around $37-38^\circ$. Including simply the height of the athlete the theory prediction goes down to about 42° for typical parameters of top athletes. Taking further the correlations of the initial velocity of the shot, the angle of release and the height of release into account we predict values around $37-38^\circ$, which coincide perfectly with the measurements. In order to achieve good performances, it is not necessary to throw at very close release angle. Throwing with high speed is more important than throwing with the optimum release angle (Lindhorn, 2001). This shows that shot put is a dynamic event demanding high power production. Many studies have shown that both lower and upper-body muscles contribute to the development of the total force value (Peng et al., 2008). The muscles of the lower limb are designed to generate power in order to impart the appropriate momentum to the whole body and to stabilize the competitor. According to Aleksić-Veljković et al. (2011) Hill's model used in the above-mentioned programs is characterized by the fact that if a passive work force is applied on the muscle, then along with the lengthening of the muscle an increase in strength over the maximum isometric strength is observed. The muscle then works under eccentric condition. When we consider the activation of the muscles throughout the entire kinematic chain the interplay of concentric and eccentric contractions decide on the mechanical energy flow in the motor system of the human body. Generation and dissipation of mechanical energy in the individual segments of the body, starting from ankle to wrist, may be a good criterion for assessing the correctness of the performance of shot put. This research confirms that the angle in comparison to throw-out height in slight inversion, but there are exceptions, which is depending on shot putter height and their motor abilities. According to Idrizović, (2010) throw-out height and trajectory on which it impacts the shot put are defined by genetic factors, firstly by body height and arm length. Therefore taller shot putters have advantage in relation to shorter in biomechanics sense as well. That can be explained by athlete's technique and their motor potentials; firstly by generating of the force in lower and upper extremities during throw-out, where from the aspect of biomechanics taller shot putters are in advantage in relation to shorter (Idrizović, 2010; Stefanović & Bošnjak, 2011). However, shorter shot putters who have good technique with good speed-strength throw-out abilities can achieve better results (Bowerman, et al. 1998; Pavlović, 2016).

According to some authors (Lanka, 2000) shot put throw-out height in top athletes is between 220 to 235 cm, while Stepanek and Sušanka, (1987) state that top athletes have better height of the throw-out because of the bigger body weight (average of 2,22 m) more than female shot putters (average of 2,07m). The results of this study do not support previous claims of authors, if we consider average results of the research. Average height of throw-out of male shot putters in this research is 2,17m (min. 1,91m to max. 2,43m,) and female average is 2,05m (min. 1,93m to 2,21m). However, if we talk about individual cases of the athletes, then the situation is different, where the throw-out height is sometimes over 2,40m. The consequences are sometimes genetic factors, and moreover in body height, arm length and throwing technique, which is in

accordance with the research (Stepanek & Sušanka, 1987; Čoh, 2002; Idrizović, 2010). Final reach (result) is in correlation with elevation and position angle, body height and body weight of the shot putters. From theory aspect, the best elevation angle of the throw-out is 45°. By increasing of the elevation, position angle decreases and vice versa. However, it is determined that optimal angle of the start of ballistic shot put flying is 30°-42°. By decreasing or increasing of the angle for 3% against the optimal, the length of the shot put trajectory increases up to 10cm. The longest trajectory is achieved when its starting point is as high from the ground as possible. Having in mind that starting point of the throw-out solely depends on the height and arm length of the shot putters, this factor remains relevant parameter for each shot putter (Pavlović, 2016).

Quotations from the theory were confirmed by current studies in terms of throw-out angle and height. Average throw out angle in male shot putters is slightly decreased (35,34°) differently from female (36,20°) which is in accordance with the research of (Linthorne, 2001, Tončev, 2001; Lenz & Rappl, 2010) and significantly lower than defined mathematical model, which is not in accordance with the research of Čoh (2002). It is not possible to accept the same speed of the throw-out of the same throw-out angle for all shot putters. When shot putter throws the shot put with a bigger angle what happens is the increase of the gravity force in the moment of the shot put detachment, which leads to throw-out speed decrease. Additionally, the structure of human body can be beneficial to force production (therefore the throw-out speed, as well) in a different way from athlete to athlete (Linthorn, 2001). Obtained results of this research showed that average throw-out speed is in a slight inverse relation in relation to throw-out angle of both subsamples. Females achieved better throw-out angle in relation to the height than males, and thus smaller throw-out speed, solely because of the gravity force (Hubbard et al., 2001). Throw-out angle represents changeable value which depends on combination of horizontal and vertical force in the moment of the throw-out, while anthropometric characteristics have very strong impact on the overall shot put movements (Pavlović, 2016).

5. CONCLUSION

Obtained results of the research confirmed statistically significant values of multiple regression function for male athletes ($R = 0,793^{**}$; $R^2 = 0,629$) and female athletes ($R = 0,806^{**}$; $R^2 = 0,650$). In male shot putters leading and direct influence of the throw-out speed is confirmed ($Beta = 0,691^{**}$), slightly less throw-out angle impact ($Beta = 0,573^{**}$) and throw-out height ($Beta = -0,526^{*}$) which was in inverse relation. In female shot putters statistically significant impact was evident in throw-out speed ($Beta = 0,528^{**}$) as a leading parameter and throw-out height ($Beta = 0,385^{**}$). It is interesting that throw-out angle in female shot putters was not defined as an influencing factor in regression function. However, in both subsamples inverse relation was recorded between throw-out speed and angle, which can be confirmed by similarly themed previous research, and that by increasing the throw-out speed throw-out angle decreases. Throw-out height proved to be relative value for which the relation with the angle and throw-out speed cannot be completely and surely defined, though average throw-out height was in a slightly inverse relation with throw-out angle in both subsamples, as a consequence of more visible impact of force of gravity. Its influence was recorded, but with no statistical significance. Additionally, average throw-out height is not in accordance with the results of some previous research (Stepanek & Sušanka, 1987; Lanka, 2000).

6. REFERENCES

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