THE DIFFERENCES IN KINEMATIC PARAMETERS OF HAMMER THROW FINALISTS OF THE 2017 LONDON ATHLETICS WORLD CUP

RAZLIKE U KINEMATIČKIM PARAMETRIMA BACAČA KLADIVA FINALISTA SVJETSKOG ATLETSKOG PRVENSTVA U LONDONU, 2017.

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ABSTRACT

Hammer throw is motor-wise an extremely complex throwing discipline with the manifestation of several different forces that impede the rotational movement of the device and the thrower in the projected sagittal plane. Kinematic parameters are one of the segments when analyzing athletic disciplines, including hammer throw. This study aims to determine spatial and time differences of kinematic parameters between male and female hammer throw finalists at the 2017 Athletics World Cup in London. The study was conducted on a sample of 24 finalists of the 2017 Athletics World Cup in London, with the aim to analyze the differences in kinematic parameters between male and female hammer throwers. The results were acquired by applying the Independent Sample t-Test. It has confirmed the differences in most of the parameters, except those regarding ejection height ($T=2,992$; $p<0,009$), where it established statistically significant discrepancies between male and female finalists. On average, the male finalists threw a hammer from a height of 1,74±0,13m, and the female finalists from 1,54±0,17m. Based on the obtained results of kinematic parameters, it can be concluded that quantitative and qualitative differences in the measured kinematic parameters of the finalists in London are evident, but that statistically significant differences are recorded only in the ejection hight of the device.

Keywords: *elite athletes, kinematic parameters, hammer throw, differences*

INTRODUCTION

Hammer throw is a compound discipline of the acyclic type, intending to throw the device as far as possible following the propositions and rules of the discipline and the competition itself. The technique is characterized by very fast integrated rotations of the thrower and the device around the vertical axis in the sagittal plane, where the thrower and the device move from the rear to the front of the circle. During the rotational movement, the competitor and the device generate high kinetic energy at a maximum speed (> 27m / s) of short duration in the ejection phase (1.6s-2.2s). The span depends on how many turns the thrower performs. Hammer throwing affects the complete musculature of the thrower, primarily the musculature of the arms and shoulder girdle, strengthening the inner and outer ligaments of the dominant kinetic chains. Competitors develop and improve motor skills, especially coordination, speed, strength, and a sense of rhythm, the so-called. proprioception (Pavlović, 2020). Throwing disciplines require a higher degree of development of certain morphological dimensions, and often because of that, with insufficiently informed subjects, the prevailing opinion is that throwers, due to their constitution, are less efficient in expressing motor skills. This established opinion is misguiding because they all have a very high level of development and manifestation of motor skills during motor movement (Milanović, 1997), where the body with a different percentage makes an important segment of it. Muscle mass is dominant (53-56%), followed by bone mass (18-22%) and subcutaneous adipose tissue (15-19%). Based on the somatotype parameters, the hammer throwers match the meso-endomorphic somatotype. Compared to other athletes, hammer pitchers are characterized by a greater amount of muscle mass, and according to Sheldon's classification, they are closer to the mesomorphic type that correlates with successful results (Pavlovic, Radinovic, & Jankovic, 2012; Pavlovic, Rakovic, Radic, Simeonov, & Piršl, 2013). From the motor-functional aspect, hammer throwing is primarily initiated by explosive activation of agonist muscles. The initial activation is followed by a period of relaxation and then deceleration due to the action of antagonist muscles as well as passive stretching of connective tissue with the integrated participation of individual motor skills. Hammer throwing is characterized by the maximum speed of movement through turns around the vertical axis in the sagittal plane until the moment of the ejection, which requires a sharp kinesthetic feeling, a high degree of motor skills, especially speed, coordination, excellent orientation during the turn, and a sense of rhythm Pavlović, 2016). In this regard, it was considered that four turns were performed by shorter and technically well-trained (faster) throwers, and three turns by stronger throwers. Today, both variants are found in all throwers, and the most common are throwers that perform four turns (Idrizović, 2010, Mihajlović, 2010). During the execution of the turn, a large centrifugal force develops and transmits to the thrower and tries to knock him down during the projected rotational movement. In order to block the fall and preserve the balance, the thrower leans to the opposite side of the device, thus creating the so-called counterweight, which means that the pitcher develops the force of the same intensity but of the opposite direction. The speed of movement of the caudal part of the body, at the end of the final stress, slows down, and the speed of the cranial part of the body increases in order to achieve a higher angular velocity of the system, i.e. the highest peripheral speed of the hammer at the moment of ejection (Pavlović, 2016). The size of the inclination of the body of the thrower on the opposite side of the hammer depends on the weight of the thrower, his physical fitness, and technical mastery. The greater the weight of the thrower, as well as their power, the lower the inclination. It would be ideal to preserve the vertical position of the body during the rotation, but this is almost impossible. This should be strived for because if the axis of rotation is left in the unchanged position, the lever rotation of the hammer increases, and in the final result, the flight distance of the device also increases (Stefanović, Bošnjak, 2011). From the biomechanical aspect, it is primary for hammer throwers to perform as high a speed as possible (through turns) in the shortest possible time interval within the limits of the support surface. In addition to the speed of rotation, the flight distance of the hammer also depends on the initial flight speed, ejection angle, and height of the ejection point (Pavlović, 2016, Mercadante, Menezes, Martini, et al. 2007), of which the ejection speed proved to be the most important (Baronietz, Barclay, & Gathercole, 1997; Štuhec, Vertič, Čoh, 2008). According to researches (Maroński 1991; Bowerman, Freeman, & Vern Gambeta, 1998), increasing the ejection speed achieves a dramatic improvement in the range of any projectile throw, where increasing the velocity by 5% increases the results by 7 meters, and changing the angle by 5% only 60 centimeters. In addition to the effect of endogenous factors on the result of the throw, gravitational, centrifugal, and Coriolis forces also make a significant contribution. Using computer modeling for typical ejection heights and optimal hammer ejection angles, the influence of Earth rotation on hammer throw and the collision of the device with air currents, air pressure, temperature, altitude, and ground inclination (Mizera, & Horváth, 2002), presented practical guidelines for correction techniques, by which the results achieved at different latitudes or with different directions of release, can be corrected by a formula that includes the effect of earth rotation, which ultimately includes phenomena that affect the functional flow of the final speed of the device. Susanka, Stepanek, Miskos, & Terauds (1986) evaluated the path of the spatial trajectory of the hammerhead and the corresponding anthropometric points from the standpoint of individual turns, two-support and one-support phases and ejection phases, studying tangential and acceleration components as well as forces acting on the device. It was found that the positive factors cause an increase in the speed of the hammerhead, including several factors. With the help of three-dimensional cinematography, Dapena, & Mc Donald (1989) proved that, in relation to the system of the mass of the thrower, the trajectory of the angular momentum vector, the inclination of the body, and the height of the plane of the hammer are interrelated. As a result, during the turn, some pitchers tilt the torso back, holding the hammer handle high, while other keep the hammer handle low and lean forward. According to Dapena, Gutiérrez-Dávila, Soto, & Rojas-Ruiz (2003), the success in the hammer throwing results is a consequence of neutralizing airflow resistance, assuming that the center of mass of the hammer coincides with the center of the ball. When throwing hammers, they use three-dimensional throwing data of male and female competitors through a simulation of a mathematical model. They proved that predicting the use of the right center of mass of the hammer reduced the deviations for men (2.39 ± 2.58m) and women (5.28 ± 2.88m), while predicting the effect of air resistance and the right center of mass of the hammer further reduced the deviations for men (-0.46 ± 2.63m), ie women's pitchers (1.16 ± 2.31m). Half of the distance loss produced by the air resistance was due to the action of forces on the ball, and the rest due to the forces exerted on the cable and the hammer handle. Increasing the force exerted on the hammer wire when turning is crucial for the throwing distance. Brice, Ness, Rosemond, Lyons, & Davis (2008) analyzed the five best hammer shots and compared the produced force acting on the hammerhead with the force measured using a stress apparatus. The results showed that the qualitative time-dependence of the two forces was basically the same, while the quantitative average difference between the measured and calculated forces during the five throws was 76N, which corresponds to a difference of 3.8% for the hammer wire force of 2000N. Also, Brice, Ness, & Rosemond (2011) analyze the relationship between force and linear velocity of a hammer wire when throwing by identifying the influence of the magnitude and direction of the force on the fluctuation of the hammer speed. The results showed a strong correlation between the decrease in linear velocity and the hammer wire force, where a strong correlation was found between the angle at which the hammer force lags in the radius of rotation towards its maximum and the magnitude of the hammer velocity decrease. Terzis, Spengos, Kavouras, Manta, & Georgiadis (2019) found that hammer throw efficiency is highly correlated with an athlete's lean body mass and higher bone mineral density, with over 66% (> 8000) of type IIa fibers in muscle structure, which is dependent on some other endogenous-exogenous factors (Ojanen, Rauhala, & Häkkinen, 2007; Judge, Bellar, McAtee, & Judge, 2010). A group of authors (Mercadante, Menezes, Martini et al. 2007) analyze the differences in kinematic parameters (angle, velocity, ejection height, velocity-time curve) between Brazilian and international pitchers, starting with the 3D trajectory of the hammerhead. The results showed the inferiority of the Brazilian pitchers compared to the international in throwing speed (average 24.59m /s men and 23.59m /s women), international (average 29.60m /s men and 28.89m /s women). The velocity-time curves of the international pitchers compared to the Brazilian show that the acceleration is higher and the deceleration lower during turns. Konz, & Hunter (2015) conducted a survey on a sample of 13 elite American throwers and 16 elite throwers of the 2003 World Athletics Finals with the aim of determining differences in throwing technique between the sexes. The results confirmed that the weight and height of the athletes, the speed of the throws, some time components, and the centripetal force were different between the sexes. Panoutsakopoulos, Vujkov, & Obradović (2012) investigate the relationship between the duration and distance of hammer throwing with three and four turns, while the relationship between the duration of the throwing phases and the hammer throwing performance is examined by adequate correlations. The results showed that there is a high and strong correlation between the throwing time of the device and the throwing distance for throwers with 4 turns ($r = -83$; $p < 0.01$) and 3 turns ($r = -.96$; $p < 0.01$). On average, most pitchers spend more time in a single-support than in a two-support stance, where the inverse relationship of the throwing distance with the total turn duration is confirmed. The results of the study confirmed the differences in all defined parameters, while statistically significant differences were recorded only in the ejection speed ($p < 0.004$) and the fourth turn speed ($p < 0.002$) in favor of men. Men threw with an average throwing speed of 27.91m/s at an average turning speed of 4.67m/s, and women 27.17m/s, with an average turning speed of 4.03m/s. The consequences of differences can be sought in the length of training, different training process, the experience of competitors, morphological profile, motor and anatomical structures, movement techniques, biomechanical parameters that were not taken into account during the research. Based on the review of previous research, and following previous results, as well as possible positive or negative trends in the development of this discipline from the aspect of qualitative and quantitative changes, the goal of current research has been defined. The aim of the research was to determine, record, and analyze possible statistically significant differences in the defined kinematic parameters between male and female hammer throw finalists of the 2017 World Athletics Championships in London.

METHOD OF WORK

The research sample includes 24 elite hammer throwing participants in the 2017 World Athletics Championships in London (12 male pitchers of average score 76.78 ± 1.65m and 12 women pitchers of average score 72.33 ± 3.29m) (Dinsdale, Thomas, & Bissas, 2018). The defined kinematic parameters of the finalist sample were taken from the IAAF official website (https://www.worldathletics.org/about-iaaf/documents/research-centre*), which confirms their originality and validity. For the purposes of the research, the following kinematic parameters of the hammer throwers were evaluated:

1. Starting speed (m/s)
2. Ejection speed (m/s)
3. Ejection height (m)
4. Ejection angle (°)
5. Speed increase through turns (m/s):

   a) Turn 1 (m s); b) Turn 2 (m/s); c) Turn 3 (m/s); d) Turn 4 (m/s)

6. Hammer path length (m):

   a) Turn 1 (m); b) Turn 2 (m); c) Turn 3 (m); d) Turn 4 (m)

7. Turn duration (s):

   a) Turn 1 (s); b) Turn 2 (s); c) Turn 3 (s); d) Turn 4 (s)

The data on the kinematic parameters of the finalists are presented in Table 1. The results obtained in the research are presented as arithmetic mean (Mean) and standard deviation (SD) by applying appropriate statistical procedures. The Independent Samples t-Test for small samples (p <0.001) was used to obtain the necessary information regarding possible differences, while the statistical program Statistica 10.0 was used for data processing.

Table 1. *Kinematic parameters of male and female 2017 World Cup finalists in London (Dinsdale, Thomas, & Bissas, 2017).*

Result mean 76,78m	**Results (m)**	**Height of velocity (m)**	**Starting velocity (m/s)**	**Increase of velocity (m/s)**				**Release of velocity (m/s)**	**Angle of velocity (°)**	**Path of the hammer during turns (m)**				**Duration of turns (s)**			
				Turn 1	**Turn 2**	**Turn 3**	**Turn 4**			**Turn 1**	**Turn 2**	**Turn 3**	**Turn 4**	**Turn 1**	**Turn 2**	**Turn 3**	**Turn 4**
Fajdek	79,81	1,69	14,6	5,2	3,8	3,1	0,9	27,7	46,2	10,6	10,1	10,9	12,3	0,66	0,50	0,45	0,48
Pronkin	78,16	1,82	17,4	4,5	2,3	3,4	-	27,6	41,9	12,5	9,8	13,3	-	0,57	0,45	0,54	-
Nowicki	78,03	1,96	15,9	4,4	3,2	2,2	2,4	28,1	39,1	10,9	10,6	11,3	13,1	0,65	0,52	0,48	0,52
Bigot	77,67	1,57	16,7	4,7	2,1	1,5	2,5	27,6	39,7	9,76	10,6	11,3	13,1	0,54	0,48	0,42	0,50
Sokyrskii	77,50	1,57	14,7	6,3	3,7	1,8	0,9	27,4	40,9	10,9	11,4	10,8	8,3	0,64	0,52	0,44	0,44
Miller	77,31	1,76	16,7	4,5	2,5	1,8	1,8	27,4	42,1	11,2	10,4	10,4	11,2	0,61	0,48	0,44	0,46
Nazarov	77,22	1,86	15,6	5,7	2,2	1,5	1,9	27,1	43,0	10,3	10,7	10,6	13,3	0,60	0,51	0,46	0,54
Marghiev	75,87	1,83	15,3	5,0	2,5	1,3	2,9	27,1	42,3	9,7	10,0	10,4	11,7	0,57	0,48	0,45	0,48
Bareisha	75,86	1,64	15,1	5,1	3,7	2,0	1,3	27,2	44,7	11,3	10,0	10,5	12,8	0,66	0,47	0,43	0,51
Lingua*	75,13	1,58	13,6	5,9	3,0	2,2	1,6	27,3	39,5	10,7	11,0	10,8	10,6	0,72	0,58	0,49	0,44
Halasz	74,45	1,78	15,2	5,1	3,5	1,7	2,0	27,5	36,7	11,6	10,2	10,7	13,5	0,71	0,51	0,48	0,55
Baltaci	74,39	1,77	14,3	4,9	3,0	2,6	2,1	26,9	39,3	10,6	9,6	9,5	12,5	0,68	0,50	0,44	0,52
Result mean 72,33m	**Results (m)**	**Height of velocity (m)**	**Starting velocity (m/s)**	**Increase of velocity (m/s)**				**Release of velocity (m/s)**	**Angle of velocity (°)**	**Path of the hammer during turns (m)**				**Duration of turns (s)**			
				Turn 1	**Turn 2**	**Turn 3**	**Turn 4**			**Turn 1**	**Turn 2**	**Turn 3**	**Turn 4**	**Turn 1**	**Turn 2**	**Turn 3**	**Turn 4**
Wlodarczyk	77,90	1,80	16,1	4,3	2,6	1,6	3,5	28,3	41,8	11,2	10,0	10,9	12,1	0,64	0,49	0,48	0,48
Wang	75,98	1,85	17,5	4,3	2,4	1,5	2,2	28,0	38,5	10,4	9,5	9,7	11,5	0,55	0,44	0,40	0,45
Kopron	74,76	1,40	15,6	5,5	2,9	2,4	1,3	27,8	39,7	9,5	9,8	10,0	11,8	0,56	0,46	0,42	0,46
Zhang	74,53	1,24	15,6	4,9	3,1	2,3	1,7	27,6	41,6	11,3	11,1	10,9	11,8	0,64	0,52	0,46	0,46
Skydan	73,38	1,64	15,1	5,0	3,0	1,3	3,8	27,8	36,9	11,3	11,5	10,4	14,2	0,68	0,57	0,48	0,60
Fiodorow	73,04	1,41	16,7	4,5	2,0	1,6	2,9	27,8	39,2	10,9	9,5	10,3	10,9	0,60	0,44	0,44	0,44
Hitchon	72,32	1,54	15,6	5,5	3,0	1,9	0,9	26,9	40,3	10,4	9,6	9,4	13,5	0,58	0,45	0,40	0,53
Šafrankova	71,34	1,69	15,5	5,8	2,6	1,5	1,3	26,8	44,4	11,9	10,7	11,5	11,7	0,66	0,50	0,50	0,48
Price	70,04	1,27	15,1	3,6	2,9	2,2	2,9	26,9	38,5	11,1	9,4	9,4	11,1	0,67	0,48	0,42	0,46
Malyshik	69,43	1,48	15,2	5,5	3,0	1,6	1,3	26,7	42,9	9,7	11,0	10,1	12,9	0,57	0,53	0,44	0,52
Klaas	68,91	1,47	16,6	4,8	3,0	1,2	0,6	26,3	42,8	10,5	9,9	10,9	10,6	0,57	0,45	0,44	0,42
Tavernier	66,31	1,64	16,9	4,3	2,3	1,9	0,5	26,0	41,2	10,7	10,7	11,1	11,0	0,58	0,50	0,48	0,46

RESULT

Table 2. *Differences between kinematic parameters of Hammer throwers (WCh London, 2017)*

		Gender	Mean	t-value	p - (2-sided)	CI% -95,00-95,00
Starting velocity (m/s)		Muale	15,43±1,10	-1,520	0,144	-1,41 to 0,22
		Female	16,02±0,79			
Increase of velocity (m/s)	Turn 1	Male	5,11±0,59	1,011	0,321	-0,27 to 0,79
		Female	4,85±0,66			
	Turn 2	Male	2,96±0,63	1,069	0,303	-0,21 to 0,65
		Female	2,74±0,36			
	Turn 3	Male	2,09±0,65	1,526	0,143	-0,12 to 0,79
		Female	1,76±0,39			
	Turn 4	Male	1,11±2,63	0,990	0,348	-8,96 to 25,34
		Female	1,92±1,12			
Release of velocity (m/s)		Male	27,41±0,32	0,645	0,536	-0,32 to 0,62
		Female	27,26±0,72			
Angle of velocity (°)		Male	41,28±2,64	0,640	0,532	-1,42 to 2,68
		Female	40,65±2,19			
Height of velocity (m)		Male	1,74±0,13	**2,992**	**0,009**	0,06 to 0,34
		Female	1,54±0,17			
Path of the hammer during turns (m)	Turn 1	Male	10,84±0,77	0,251	0,801	-0,55 to 0,70
		Female	10,76±0,71			
	Turn 2	Male	10,37±0,52	0,554	0,597	-0,40 to 0,68
		Female	10,22±0,74			
	Turn 3	Male	10,88±0,90	1,484	0,155	-0,19 to 1,16
		Female	10,39±0,69			
	Turn 4	Male	12,04±1,54	0,189	0,859	-1,05 to 1,26
		Female	11,93±1,10			
Duration of turns (m/s)	Turn 1	Male	0,63±0,06	1,181	0,253	-0,02 to 0,07
		Female	0,61±0,05			
	Turn 2	Male	0,50±0,03	0,938	0,362	-0,02 to 0,05
		Female	0,49±0,04			
	Turn 3	Male	0,46±0,03	0,930	0,361	-0,02 to 0,04
		Female	0,45±0,03			
	Turn 4	Male	0,49±0,04	0,705	0,480	-0,03 to 0,05
		Female	0,48±0,05			

Abbreviation: Mean (average value), standard deviation (St.Dev), coefficient t-test (t-value), Sig.level (**p<0,001), CI% = confidence interval

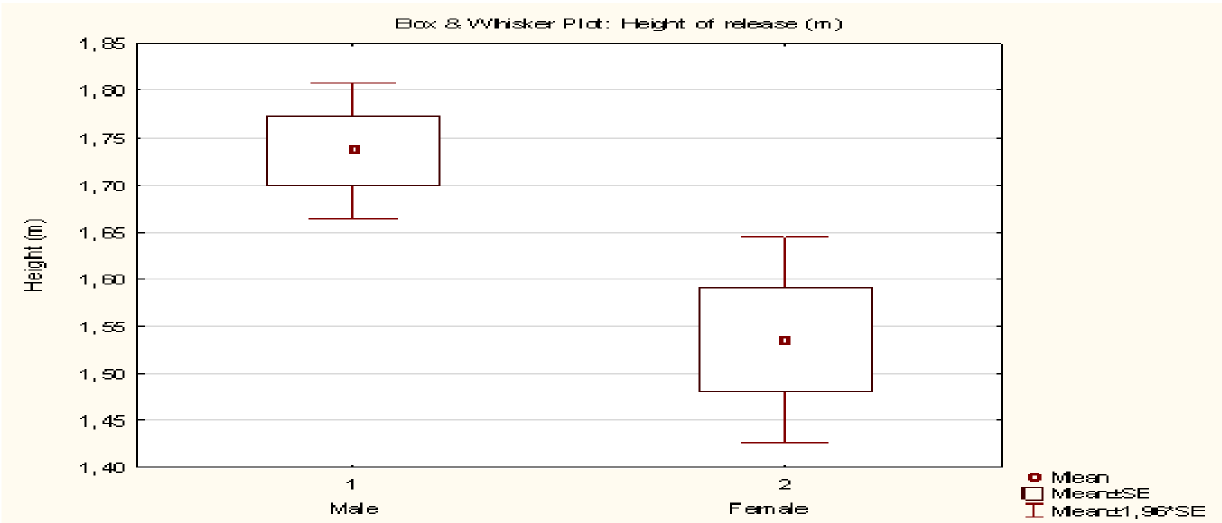

Figure 1. *The differences between finalists in* Height of release (m)

Analyzing the numerical values of the kinematic parameters, quantitative differences in all measured parameters between finalists of different sex were recorded (Table 2). Compared to men, female finalists achieved higher starting speed (16.02m/s), higher speed in the fourth turn (1.92m/s) and longer hammer path in the third turn (10.88 m), but shorter average turn duration (2.03s), as well as lower ejection angle (40.65 °). In the rest of the kinematic parameters, men showed better numerical values. Statistically significant differences were recorded only in the ejection height parameter (T = 2.992; p <0.009) in favor of male competitors (1.74 m) versus female (1.54 m) (Table 2; Graph 1, 5). This was expected given the pronounced longitudinality within the morphological status of the male finalists. By the same token, female finalists with their lower longitudinality and lighter device, managed to perform the turns in a shorter time interval compared to men (Table 2). The average hammer ejection speed of the male finalists in London was 27.41 m/s, which is only 0.15 m/s faster than the female finalists, while the ejection angle was with a minimal difference (Table 1, 2 Fig. 1). The highest throwing speed was achieved by the third-placed Nowicki (28.1 m/s), who threw the hammer at an angle of 39.1 ° and a starting speed of 15.9 m/s, which proved the inverse relationship between the speed and the ejection angle.

The individual starting speed of the male finalists ranged from 13.6 m/s (Lingua) to 17.4 m/s (Pronkin) and the ejection speed from 26.9 m/s (Baltaci) to 28.1 m/s (Nowicki). The male finalists entered the first turn at an initial velocity of 15.43 m/s, and 27.41 m/s at the moment of ejection. It turns out that during four turns, the speed increased by 11.98 m/s with significant oscillations in the speed in all turns. The speed increased with the number of turns, which is the goal of every hammer thrower, to achieve the maximum speed at the moment of ejection. The hammer was thrown with an average ejection angle of 41.3 °, ranging from a minimum of 36.7 ° (Halasz) to a maximum of 46.2 ° (first-placed Fajdek) (Tabela 1, Grafikon4). The men threw hammers from an average height of 1.74m, ranging from a minimum of 1.57m (Bigot, Sokyrskii) to a maximum of 1.96m (Nowicki). Male finalists achieved a longer average hammer path through turns (44.13m) of average duration (2.08s) compared to female finalists (43.30m) of 2.03s. More than 90% of the finalists achieved the average longest hammer path in the last fourth turn (Halasz 13.5m; Skydan 14.2m) (Table 1, 2, Graph 4, 5).

Among the female pitchers, the first-placed Wlodarczyk achieved the highest initial hammer ejection speed (28.3 m/s), at an ejection angle of 41.8 ° and a starting speed of 16.1 m/s. Also, the female finalists achieved a lower starting speed compared to the male finalists, ranging from 15.1m/s (Skidan, Price) to 17.5m/s (Wang) with a tendency to increase in the last turn. Also, women were inferior in terms of individual results of ejection velocity from 26.0 m/s (Tavernier) to 28.3 m/s (Wlodarczyk) and average initial velocity of 16.02 m/s (Table 2; Graph 4, 5). During the four turns, this speed increased by 11.24 m/s with significant oscillations in the speed of rotation, identical to the male finalists. The average ejection angle of women was 40.65 °, with a maximum of 44.4 ° (Shafrankova) and a minimum of 36.9 ° (Skydan).

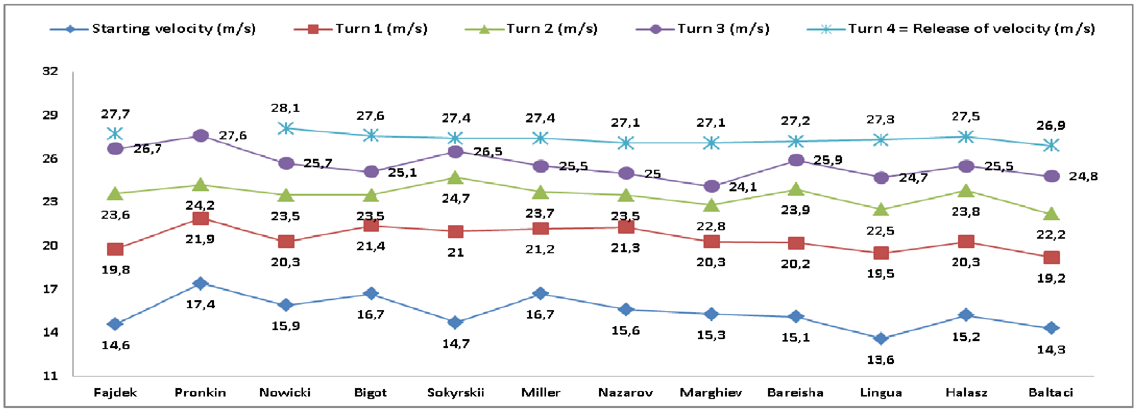

Figure 2. *Speed fluctuation during the turn (male finalists)*

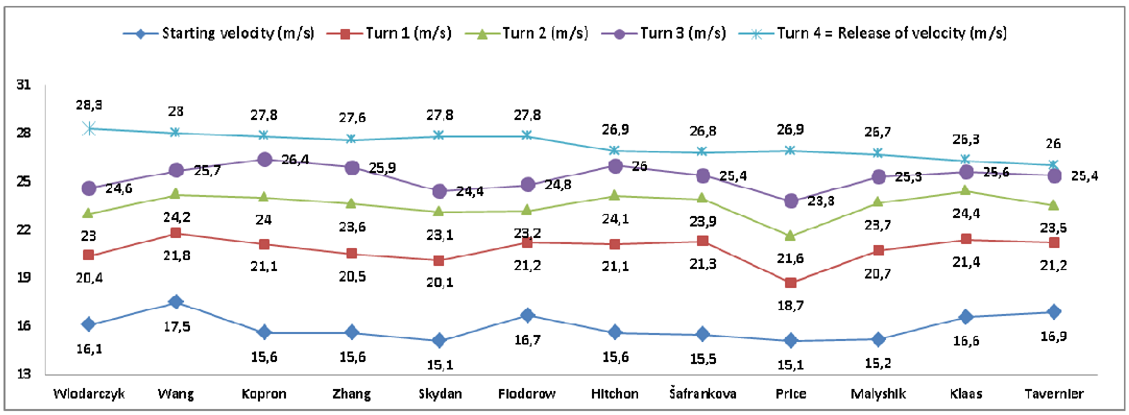

Figure 3. *Speed fluctuation during the turn (female finalists)*

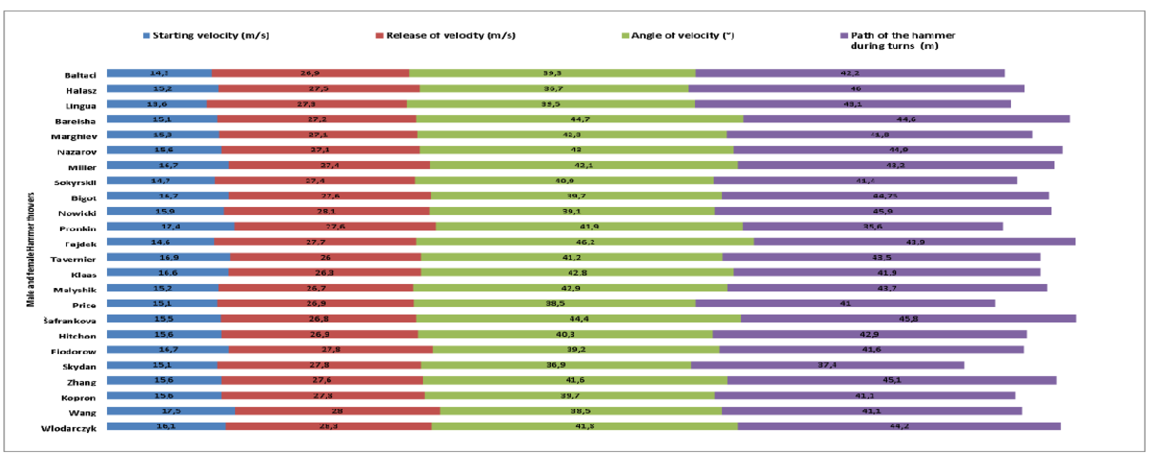

Figure 4. *Distribution of individual results of kinematic parameters of finalists (starting speed, ejection speed, ejection angle, hammer trajectory)*

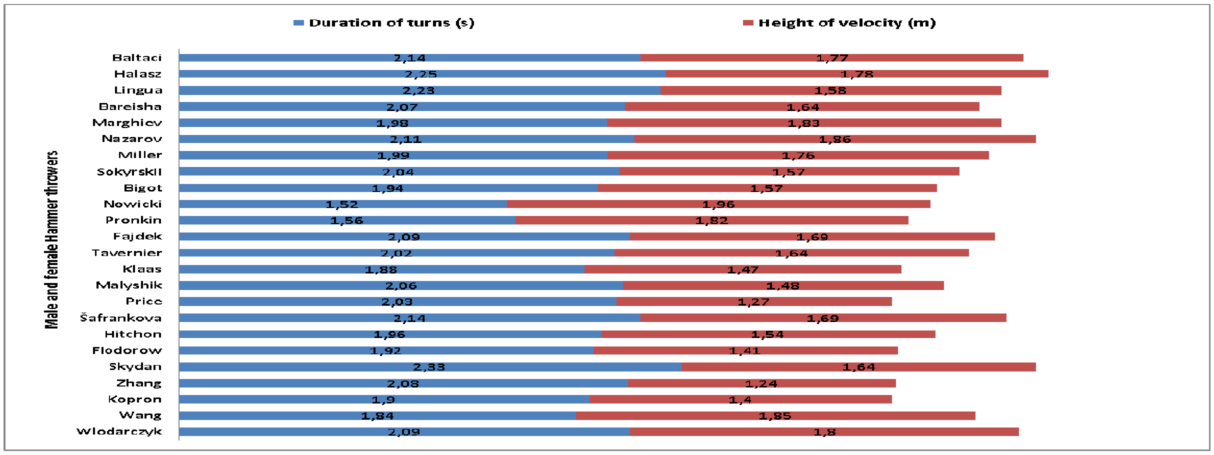

Figure 5. *Distribution of results of kinematic parameters of finalists (turn duration, ejection hight)*

DISCUSION AND CONCLUSION

The main goal of the research was to determine the differences of kinematic parameters between male and female finalists of the 2017 World Athletics Championships in London. The obtained results confirm significant differences between the sexes, representing the main result of the research.

However, a statistically significant difference was found only in the ejection height (Table 2, Chart 1).

Among throwing disciplines, hammer throwing is considered to be one of the most complex competitions in terms of coordination, technique, as well as the difficulties that arise in training and creating a correct dynamic stereotype. All of the previously mentioned requires the participation of different forces, the harmony of movement and depends on the components of the training process, continuous training, and years of experience (Judge, Bellar, Mc Atee, et al. 2010; Saad Fathallah Mohamed Elalem, 2016; Pavlović, 2020). The hammer throwing technique depends on achieving the maximum speed of the device through turns to the moment of the ejection, ejection angle, and ejection height. During the performance, there is an integrated rotary movement in the thrower – hammer interaction. It constantly rotates around an axis passing between the center of gravity of the thrower's body and the device, as well as through the support and the base (Maheras, 2009; Shesterova, & Rozhkov, 2018). Each movement begins with the initial swinging of the thrower which creates the conditions for entering the first turn, whereby the thrower achieves the necessary rhythm and good concentration which is important for further stages of the technique. The number of turns performed primarily depends on the training of the thrower, his anatomical and physiological structures, and motor skills (Terzis, Spengos, Kavouras, et al. 2010). Then follow the swings where the competitor rotates together with the hammer around the vertical axis. During the hammer swing, the initial speed of rotation (12-16m/s) is noted and the common center of gravity of the system (thrower-hammer) must be within the surface of the support (Mihajlović, 2010; Pavlović, 2016). The results of the current research are in line with the above, where the average starting speed of the female finalists in London was 16.02m/s, and the male's 15.43m/s. Compared to the results of the research (Pavlović, 2020), men in London achieved a lower average starting speed by 1.26 m/s and women by 0.22s, than the finalists in Daegu. According to some authors (Panoutsakopoulos, Vujkov, Obradović, 2012; Konz, & Hunter, 2015) in the phase of overtaking the device, the movement of the thrower is mainly aimed at achieving the highest possible speed, when the thrower and hammer perform a complex rotational movement around vertical axes as one system. In doing so, they move together in the sagittal plane of the circular segment at maximum speed, in order to achieve the maximum speed of action on the device in the ejection phase (Štuhec, Vertič, & Čoh, 2008). The average ejection speed of the male finalists in London (27.41m/s) represents a better result than the female finalists (27.26m/s), but without statistical significance (Table 2). Compared to the male finalists in Daegu in 2011, the men's result is lower by 0.50m/s, while the women achieved a higher speed than the women's finalists in Daegu (by 0.9m/s). Although the differences in ejection speed are numerically small, they have a positive effect on the total throw length. The quality of the thrower's turn is highly correlated with the quality of coordination and records an increase in rotation speed with a linear increase in strong centrifugal force (more than 4000N) affecting the stability of the thrower and the projection of their trajectory. The thrower opposes the action of force by tilting the body backward with compensatory movements of caudal extremities, lowering the center of gravity of the body (Pavlović, 2016). In order to perform the swing in as large a radius as possible, the thrower softly makes turns in the joints of the spine and hips so that when the hammer moves away from the body, the thrower moves the pelvic part of the body to the opposite side of the device, thus creating preconditions for the beginning of the second or third momentum (Idrizović, 2010; Mihajlović, 2010, Stefanović and Bošnjak, 2011; Pavlović, 2020). As both the thrower and device rotate, the speed of the device increases progressively until it reaches the moment of ejection at over 27 m/s and the perfect ejection angle 40°, though some throwers eject at the angle of 38° to 40° (Bowerman i et all. 1998; Konz i Hunter, 2015). However, some authors (Mihajlović, 2010, Stefanović and Bošnjak, 2011; Dapena, 1984) believe that the angle depends on the height of the athlete and ranges from 42 to 44 °, which is contrary to the results of this research. The average throwing angle of the finalists in London is 41°, with higher or lower individual values of the competitors, which is in line with the indications (Pavlović, 2020) and is inversely related to the height of the throwing device. It is known that hammer throwing is characterized by a complex spatio-temporal structure, with the aim of achieving a maximum speed of movement through swings and transition to 3, 4, or 5 turns, while moving linearly through the center of the circular segment. Such movement further complicates the changes in the spatial orientation of the planes that define the trajectory of the hammer in each turn (Gutiérrez-Davila, Soto, Rojas-Ruiz, 2002). Each pitcher goes through a two-support period (entry of the thrower into the turn) and a single-support period (exit of the thrower from the turn) in one turn. It is commonly believed that the acceleration of the hammer is achieved in the phase of two-support contact (traction force of the hammer directed downwards and forwards, which builds the stability of the thrower and achieves a higher speed), and not single-support (traction force of the hammer is very strong and the thrower opposes it by positioning their body opposite of the position of the device. Both phases are of very short duration (0.20-0.26s), and decrease as the thrower goes from the first to the fourth turn (Pavlović, 2020). During rotation, while the speed increases, the distance between the feet decreases. The individual results of the finalists partially confirmed that the initial speed was 16m/s while at the moment of ejection the speed reached over 28m/s. Some coaches have tried to extend the two support phase to improve the score (30.31). The theory is proved by the marked fluctuation of the hammer speed in both two-support period and a noticeable decrease in the single-support period. However, Dapena, & McDonald (1989) question this theory, because they proved that the speed increases in the single-support period, believing that the impact of the thrower on the speed of the hammer is not negative, even when the thrower pulls the hammer towards the body because it comes from the highest point path. In our sample, there is a fluctuation of speed through turns, where the male finalists recorded a slightly higher average speed in the first, second and third turn (Turn 1 = 5.11m/s; Turn 2 = 2.96m/s; Turn 3 = 2 , 09m/s) in relation to women (Turn 1 = 4.85m/s; Turn 2 = 2.74m/s, Turn 3 = 1.76m/s), and the fourth turn is dominated by women's finalists (Turn 4 = 1.92m/s). These results are in contrast to the results of the finalists in Daegu, 2011, where women had a higher turning speed (Pavlović, 2020). They are a consequence of the different synchronization of the neuro-motor activity of the thrower, proprioception, the length of the levers, and the weight of the device. According to some researchers (Pavlović, 2016; Mihajlović, 2010, Stefanović and Bošnjak, 2011), the turning of the hammer begins at the moment when the device is on the right side of the thrower, below shoulder height. At the moment of passing over the arch of the left foot, the speed of the hammerhead is the highest, and thus the strongest centrifugal force, which requires the inclination of the thrower to maintain an equilibrium position. When entering the first turn, the shoulders and hips are parallel. However, when exiting the turn and moving to the one-support period, the hips move faster, overtaking the device, in order to achieve the fastest possible two-support period, and completing the first turn, generates a large torque (Dapena, Mc Donald, 1989). In this phase, the thrower strives to achieve the best anatomical-biomechanical parameters for the most efficient and most favorable entry into the next turn by synchronized myometric-plyometric muscle contractions through kinetic muscle chains. Thus, the hammer must enter the second turn at a higher speed than the entry into the first, which was confirmed by the results of this survey of the finalists in London (Table 2, Graph 2.3). The same principle is applied when entering and exiting the next three or four turns. This theory was confirmed in our study for both subsamples, where, from turn to turn, after the starting speed of about 16m/s, the ejection speed increased by 11m/s successively, reaching the maximum speed in the fourth turn in the ejection phase (Table 1, Graph 2 , 3, 4), which is in line with the research [Štuhec, Vertič, Čoh, 2008; Pavlović, 2020].

Men in London had a higher average speed increase through turns (11.43m/s) than women finalists (11.24m/s) and were also more successful than finalists in Daegu, 2011 (men 11.22m/s; women 10, 93m/s).
However, on average, male and female finalists in Daego achieved higher starting and ejection speed than the London finalists, which resulted in a better ranking.

The movement of the hammer starts with several swings which are followed by turns in which the thrower rotates synchronously. The speed of the hammer is constantly increasing until the moment of ejection (Maheras, 2009). What is then being observed is the circular motion of the hammer around the thrower, the gradual change in the inclination of the plane of motion of the hammer, and the horizontal trajectory of the thrower-hammer system within the circle. In the initial part of the throw, the hammer is in a horizontal trajectory of 37 ° (Stefanović, Bošnjak, 2011), but it becomes steeper as the speed increases and reaches an inclination of about 40 ° during the last turn. The pitcher keeps the hammer on its circular trajectory while, during the last turn, the centrifugal force is transmitted through the wire to the center of the ball. During the turn, the wire acts equally and opposite to the force of the thrower's hands, which tends to pull him forward (Dapena, McDonald, 1989; Mihajlović, 2010; Brice, Ness, Rosaemond, 2011). The duration of turns of elite throwers depends on the number of turns and the increase in speed, ranging from 1.64 sec. (with 3 turns) up to 2.16 sec. (with 4 turns). For example, when achieving results over 80m, Murofushi performed 4 turns in 1.96 sec, Tikhon in 2.04 sec, etc. The ejection speed, if achieved at the appropriate angle, is almost always a decisive factor in the final result (Pavlović, 2016; Idrizović, 2010). The first-place winner in London (Fajdek, 79.81 m) threw a hammer at a speed of 27.7 m/s at an angle of 46.2 °, while the female winner did the same (Wlodarczyk 77.90 m) at a speed of 28.3 m/s and an angle of 41, 8 °. The inverse relationship between the ejection speed and the ejection angle was present at all times. The research results of the 2011 Daego World Championship finalists confirmed that the ejection speed is inversely related to the ejection angle.

When throwing hammers, the action on a longer path is not a guarantee of a good result, but it is necessary to achieve the maximum force in the shortest time interval (Panoutsakopoulos, Vujkov, Obradović, 2012), which is confirmed by this research (Table 1). Each sex has characteristics that contribute to success because there are distinct anthropometric differences between them probably affect the optimal technique (Konz and Hunter, 2015), which can be confirmed in the results of this research. The most visually noticeable differences are in height and body weight, where male hammer throwers are typically taller and have a higher mass than their counterparts (Pavlović, et al. 2012; Pavlović, et al. 2013). The male hammer is proportionally more massive than the female hammer which results in a different manner of overcoming the force of inertia and centrifugal force. Therefore, female pitchers have a higher starting speed due to lower body weight, shorter torso, and lower ball weight, as well as the center of mass of rotation due to the difference in weight and mass distribution during turns and throws (Bartonietz, Barclay, Gathercole, 1997; Dapena, Gutiérrez-Dávila , Soto, & Rojas-Ruiz, 2003; Knudsson, 2003), which was also confirmed in this study, where women had on average a higher starting speed (16.02m / s) than men (15.43m / s) so they need less effort than men when confronting forces of inertia and centrifugal force (Ransdell, & Well, 1999; Bartonietz, 2004; Dapena, 1986).

The research was conducted on a sample of 24 finalists of the World Athletics Championships in London in 2017, with the aim of determining the differences in kinematic parameters between male and female hammer throwers. The results of the research confirmed the differences in all defined parameters, while statistically significant differences of the finalists were recorded only in the ejection hight (T = 2.992; p <0.009). Male finalists achieved a higher ejection height (1.74 ± 0.13m) than female finalists (1.54 ± 0.17m). The results obtained in this study are partially consistent with the results of some previous studies, and depend on the parameters being analyzed.

REFERENCES

Baronietz, K., Barclay, L., & Gathercole, D. (1997). Characteristics of top performances in the women's hammer throw: basics and technique of the world's best athletes. *New Studies in Athletics, 12*(2-3), 101-109.

Brice SM, Ness KF, Rosemond D, Lyons K, &Davis M. (2008). Development and validation of a method to directly measure the cable force during the hammer throw. *Sports Biomechanics. 7*(2), 274-87.
https://doi.org/10.1080/14763140701841902
PMid:18610778

Brice, SM., Ness, KF &Rosemond, D. (2011).An analysis of the relationship between the linear hammer speed and the thrower applied forces during the hammer throw for male and female throwers. *JournalSports Biomechanics.10,* (3), 174-184.
https://doi.org/10.1080/14763141.2011.592210
PMid:21936287

Bartonietz, K. (2004). Arremesso de martelo: problemas e perspectives. In Zatsiorsky, V.M., Biomecânica no Esporte. (pp 358-380). Rio de Janeiro: Guanabara-Koogan.

Bowerman, W.J., Freeman, W,H. & Vern Gambetta T.A.C. (1998). Atletika (prevod).Zagreb-Gopal.

Dapena, J. (1986). A Kinematics Study of Center of Mass Motion in the Hammer Throw. Jounal of Biomechanics, 19(2), 147-158.
https://doi.org/10.1016/0021-9290(86)90144-2

Dapena, J., & McDonald, C. (1989).A three-dimensional analysis of angular momentum in the hammer throw. *Medicine and Science in Sports & Exercise, 21*(2), 206-220.
https://doi.org/10.1249/00005768-198904000-00015
PMID: 2709984

Dapena,J., Gutiérrez-Dávila,M., Soto, V &Rojas-Ruiz, F. (2003). Prediction of distance in hammer throwing. *Journal of Sports Sciences 21* (1), 21-28.
https://doi.org/10.1080/0264041031000070921
PMid:12587888

Dapena, J. (1984). The Pattern of Hammer Speed During a Hammer Throw and Influence of Gravity on its Fluctuations. *Journal of Biomechanics, 17*(8), 553-559.
https://doi.org/10.1016/0021-9290(84)90086-1

Dinsdale, A., Thomas, A., and Bissas., A., &Merlino, S. (2018). Biomechanical report for The 14 IAAF World Championship London 2017 Hammer Throw Men's and Women's, Final report Hammer Throw. Scientific Research Project Biomechanical Analyses at the 14 IAAF World Championship, London, 2018.

Gutiérrez-Davila, M., Soto, V.M., &Rojas-Ruiz, F.J. (2002). A biomechanical analysis of the individual techniques of the hammer throw finalists in the Seville Athletics World Championship 1999.New studies in Athletics, 17 (2), 15-26.

Idrizović, K. (2010). Atletika I,II - udžbenik. Biblioteka biomedicinksih istraživanja.Podgorica.

Judge, L., Bellar, D., McAtee, G., & Judge, M (2010). Predictors of Personal Best Performance in the Hammer Throw for U.S. Collegiate Throwers. *International Journal of Performance Analysis in Sport.10,* (1), 54-65. https://doi.org/10.1080/24748668.2010.11868501

Konz, S., &Hunter, I. (2015).Technique Comparison Of Male And Female Hammer Throwers. 33 International Conference of Biomechanics in Sports (2015). Floren Colloud, Mathieu Domalain & Tony Monnet (Editors) Coaching and Sports Activities, pp.1038-1041.

Knudson, D. V. (2003). Fundamentals of Biomechanics New York: Kluwer Academic/Plenum Publishers. https://doi.org/10.1007/978-1-4757-5298-4

Milanović, D. (1997).Teorija treninga-priručnik za sportske trenere. Zagreb: Fakultet za kineziologiju.

Mihajlović, I. (2010). Atletika-udžbenik. Novi Sad: Fakultet sporta i fizičkog vaspitanja

Mercadante, LA., Menezes, RP, Martini, TP., Trabanco, JLA., &Leite de Baros, RM (2007). 3D Kinematical Analysis Of The Hammer Throw In Competitions. 25 International Symposium on Biomechanics in Sports, Ouro Preto - Brazil pp.314-31.

Maroński R. (1991). Optimal distance from the implement to the axis of rotation in hammer and discus throws. *J Biomech. 24*(11), 999-1005.
https://doi.org/10.1016/0021-9290(91)90017-H

Mizera, F, &Horváth, G.(2002). Influence of environmental factors on shot put and hammer throw range. *Journal of Biomechanics. 35* (6), 785-796.
https://doi.org/10.1016/S0021-9290(02)00029-5

Maheras, A. (2009). Reassessing velocity generation in hammer throwing. New studies in Athletics 24 (4), 71-80.

Ojanen T, Rauhala T, &Häkkinen K. (2007) Strength and power profiles of the lower and upper extremities in master throwers at different ages.*J Strength Cond Res. 21*(1), 216-222.
https://doi.org/10.1519/00124278-200702000-00039
PMid:17313300

Pavlovic, R., Radinovic, Z., & Jankovic, M.(2012). Morphological status of finalists in the throwing disciplines at the Beijing Olympics. *Sportmont, 10* (34-36), 447-455.

Pavlovic, R., Rakovic, A., Radic, Z., Simeonov, A., & Piršl, D. (2013). Morphological status of female athletes in throwing disciplines at the Olympic games in Beijing. Research In Physical Education, *Sport And Health, 2* (2), 113-119.

Pavlovic, R. (2016).Atletika 1- udžbenik. Niš.Udruženje književnika Branko Miljković.

Pavlović, R. (2020). Differences in kinematic parameters between male and female hammer throw finalists of the World Championship in Daegu in 2011. *Pedagogy of Physical Culture and Sports, 24*(5), 255-263.
https://doi.org/10.15561/26649837.2020.0506

Panoutsakopoulos V., Vujkov N., &Obradović B. (2012). The duration of the throw is correlated with the throwing distance in men's and women's hammer throwing with three and four turns. Modern Athlete and Coach [Australian Track & Field Coaches Association], 50 (1), 33-39.

Ransdell, L. B., & Well, C. L. (1999).Sex differences in athletic performance.*Woman in Sport & Physical Acitivty Journal, 8*(1), 55-81.
https://doi.org/10.1123/wspaj.8.1.55

Stefanović, Đ. & Bošnjak, G (2011).Atletika, filosofsko-naučne osnove i primena u praksi. Banja Luka: Fakultet fizičkog vaspitanja i sporta.

Susanka, P., Stepanek, J., Miskos, G., &Terauds, J. (1986).Hammer-Athlete Relationship During The Hammer Throw, 4 International Symposium on Biomechanics in Sports, pp.194-200.

Saad Fathallah Mohamed Elalem (2016). Evaluation of Hammer Throw Technique for Faculty of Physical Education Students using DartFish Technology. *Journal of Applied Sports Science, 6* (2), 80-87.
https://doi.org/10.21608/jass.2016.84559

Shesterova, L., & Rozhkov, V. (2018). Interrelation of the hammer swing technique with the technique of its previous rotation in highly skilled hammer throwers. *Slobozhanskyi herald of Science and Sport. 6* (68), 13-16.
https://doi.org/10.15391/snsv.2018-6.003

Terzis, G., Spengos, K., Kavouras, S., Manta, P, &Georgiadis G.(2010). Muscle fibre type composition and body composition in hammer throwers. J Sports Sci Med. 9 (1), 104-109.
PMID: 24149393

Ugarković, D. (1996). Biologija razvoja čovjeka sa osnovama sportske medicine. Beograd: Fakultet fizičke kulture.

Štuhec, S., Vertič, R., & Čoh, M. (2008). 3D kinematic analysis of the hammer throw-Primož Kozmus. In monograph M.Čoh (ed.), Biomechanical diagnostic methods in athletic training (85-91). Ljubljana: Faculty of Sport, Institute of Kinesiology.

THE DIFFERENCES IN KINEMATIC PARAMETERS OF HAMMER THROW FINALISTS OF THE 2017 LONDON ATHLETICS WORLD CUP

SAŽETAK

Bacanje kladiva je motorički vrlo kompleksna bacačka disciplina sa manifestacijom više različitih sila koje nastoje da onemoguće rotaciono kretanje sprave i bacača u projektovanoj sagtalnoj ravni. Kinematički parametri su jedan od segmenata u analizi atletskih disciplina, uključujući i bacanje kladiva. Cilj studije bio je da se utvrde prostorne i vremenske razlike kinematičkih parametara između muških i ženskih finalista, bacača kladiva Svjetskog prvenstva u Londonu. Studija je sprovedena na uzorku 24 finalista Svjetskog prvenstva u Londonu, 2017, sa ciljem analize razlika kinematičkih parametara između muških i ženskih bacača kladiva. Da bi se dobili potrebni rezultati primenjen je t-test za male nezavisne uzorke. Rezultati su potvrdili razlike u većini mjerenih parametara ali statistički značajne razlike između muških i ženskih finalista su potvrđene samo u visini izbačaja (T=2,992; p<0,009). Muški finalisti su bacali kladivo u prosjeku sa visine 1,74±0,13m, a žene sa 1,54±0,17m. Na osnovu dobijenih rezultata kinematičkih parametara može se zaključiti da su evidentne kvantitativne i kvalitativne razlike u mjerenim kinematičkim parametrima finalista u Londonu, ali da su statistički značajne razlike evidentrane samo u visini izbačaja sprave.

Ključne riječi: *elitni sportisti, kinematički parametri, bacanje kladiva, razlike.*

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