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The Differences of Kinematic Parameters Javelin throw between Male and Female Finalists World Championship (Berlin, 2009-Daegu, 2011)

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Abstract **Background**: Kinematic parameters are an indispensable segment in the analysis of all throwing disciplines, including javelin throw. They are also an indicator of possible differences between competitors of different or the same rank of the competition and are an important factor for achieving a good result. **The aim** of the study was to determine the spatial and temporal differences of kinematic parameters in the javelin throw between the male and female finalists of the World Championships. **Methods**: The study was conducted on a sample of finalists in the World Athletics Championships (Berlin 2009-Daegu 2011) with the aim of determining the differences between the kinematic parameters of the male and between the female javelin throwers. The sample included a total of 32 competitors in both categories. To obtain the necessary results, a t-test for independent samples was applied. **Result:** statistically significant differences were confirmed between male finalists in 60% of kinematic parameters: release velocity ($t=3{,}504$; $p<0{,}004$), angle of yew ($t=4{,}664$; $p<0{,}000$), length of delivery stride ($t=2{,}444$, $p<0{,}028$), distance to foul line ($t=5{,}120$), duration of impulse stride ($t=-4{,}462$, $p<0{,}001$), duration to release ($t=-4{,}837$, $p<0{,}000$). In women, significant differences in 40% of parameters were confirmed: angle of release ($t=-{,}365$, $p<0{,}005$), angle of yew ($t=9{,}182$; $p<0{,}000$), duration of impulse stride ($t=-4{,}140$, $p<0{,}001$), duration to release ($t=-4{,}409$, $p<0{,}001$). **Conclusion:** Generally speaking, this research showed that significant differences were observed between male finalists and between female finalists. Mostly, these are kinematic parameters that have proven to be paramount in the resultant performance of these championship throwers. One should not forget the influence of exogenous factors, above all air currents and javelin behavior as an aerodynamic device. An ideal biomechanical model of the thrower can be made based on the differences in the kinematic parameters of the top medal winners at the Berlin WCh in 2009 and the Daegu WCh in 2011.

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

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1. Introduction

In addition to racing disciplines, javelin throw can be said to be a competition with the longest tradition in athletics and sports in general. No object in human history has remained in use as long as a javelin, so it can be said to be the oldest sporting device. Javelin throw developed as a sport first among the Nordic countries. It was not until the London Olympics in 1908 that the discipline was officially entered into the men's Olympic program and in 1932 in Los Angeles into the women's program. The first winner of the 1908 London Olympics was Swedish competitor Eric Lemming (54,30m) and was the first athlete to link racing with throwing steps. In 1986, new javelins were introduced in male category with new features, and in 1999 in female category. Due to the results that were achieved, both the male and female javelins were later redesigned, with the centre of gravity of the spear moved 4cm forward to avoid extremely long shots that could endanger the audience (U. Hohn 1984, threw 104,80m). The famous Swedish javelin-maker Nordic Sport has done a great deal of testing in the past, comparing the new with the old javelins. The results showed that the average discharge velocity of 28.3m/s from the so-called guns, the old spear reached a length of 84,60m, and the new reached 79,58m with a difference of 5,9%. This difference was 8,1% and even greater when thrown by athletes, which led to the opinion of the then coaches that the new javelins required more power than technique [1].

Compared to other athletes in the throwing disciplines, javelin throwers are dominating by a meso-ectomorphic somatotype. Of all throwing disciplines, javelin throwers have the smallest quantitative morphological parameters, which correspond to the technique of execution and the weight of the device itself. They have a slightly higher level of manifestation of individual motor skills than shot putters, discus throwers and hammer throwers. Compared to other throwing disciplines, much lower numerical values of the defined morphological parameters are observed and these athletes do not belong to the group of overweight people. Mostly active mass is more developed, instead of a ballast one. Pavlovic et al. [2,3] analysed the morphological profile of male and female javelin throwers at the 2008 Beijing Olympics finalists, among other throwing disciplines. The results obtained confirmed the previous allegations of dominance of the meso-ectomorphic type. However, in addition to the morphological and motor parameters, the biomechanical parameters of the javelin throwers have great impact on the resultant success. First of all, the height, angle and speed of the ejection, the angle of deflection, the length of the individual steps, the position of the knee at the ejection, etc., and all of them, more or less, participate in the placement of competitors. US authors [4] carried out a project to investigate elite javelin throwers in the US, including world record holder Tom Petranoff (99,72m). Using a high speed video camera (Spin Physics SP2000), among other throwers, the recorded ejection rate that Petranoff achieved (32,3m/s) is one of the highest values ever recorded. The javelin position was 36,66° and the attack angle was 4°. These results served as a benchmark for the performance of all future javelin throwers with an emphasis on ejection speed. The importance of the rate of ejection in the last seconds was confirmed [5] by analysing the biomechanical factors of the critical performance of male throwers. They state that elite javelin throwers develop as much as 70% of the ejection velocity in the last 0.1 seconds, which is the link between good results and the speed of force development in a short time interval. It is the movements of the thrower in the ejection phase, the moment of the last foot strike on the ground and its ability to transfer impulse between the lower and upper body, as well as the coordination of the whole body in relation to the device, that are closely related to the result success. They suggest that the increase in speed can be optimized by transferring the force to a javelin with a short duration to maximize its momentum, which is correlated with the physical ability, i.e. the coefficient of force generated by its engaged muscles. Some other researchers have who analysed the kinematics of competitors agree that he successful throwing of a javelin is a consequence of the high ejection velocity, the length of the last step, less flexion of the knee of the ejection leg, the position of the pelvis, shoulder, and elbow of the ejection arm [6].

An interesting study was conducted by a group of authors [7] with the aim of clarifying the kinematic characteristics of the javelin throwing movement. They analysed the best results of eight men's finalists in the World Athletics Championships and 49 Japanese men's throwers. The results of the study confirmed the importance of the speed of ejection and greater speed of World Cup finalists than other throwers. They concluded that the finalists were approaching at a higher speed and had, during the final phase, an anterior leg angle in the extension position to convert the approach speed into forward torso rotation. They also found that during forward rotation of the torso, the angle at the elbow joint and the shoulder separation angle, at the moment of ejection, are also small, in order to more effectively transfer the internal velocity of rotation of the shoulder joint to the moment of ejection. Also, the study [8] analysed the results between two groups of throwers. Significant positive correlations were observed ($p<0,001$) between the initial velocity and the approach speed on the one hand, and between the approach velocity and the ejection velocity on the other. The (EG) group with higher scores (>70m) showed a significantly lower angular flexion rate of the supporting leg knee compared to the (OG) group that had lower scores (70m<). The study revealed several new technical details related to javelin throwing, which can certainly help improve javelin throwers' performance. The conclusion is that, first, it is necessary to convert the horizontal velocity of the centre of mass of the body into the rotational velocity of the body while maintaining an extended position in the locking leg, which may help to achieve a high initial velocity of the pitcher. A study has shown that javelin throwing is kinematically extremely complex and not always in line with the references in the literature [9]. They determined the general sequences of upper and lower extremity movements on more than 60 Japanese elite, male and female javelin throwers during the competition. More than 15 three-dimensional upper and lower extremity kinematic data and their start times were collected. The results showed that the movements of the upper and lower extremities of the elite throwers followed certain sequences but not a proximal sequence towards the distal one, which deviates from the references in the literature. It concludes that further studies are needed to determine the effect of upper and lower extremity movement sequences on knee ejection performance. It follows that the primary goal of javelin throw training is to develop high running speed during run-up and explosive power that would result in high ejection speed. Previous biomechanical testing of javelin throwing has mainly focused on release parameters such as initial velocity, release angle, attitude angle, attack angle, and discharge height [10]. These studies have found that high discharge rates are a key factor in achieving peak performance. Furthermore, other researchers evaluated data from the 1992 Olympic Games [11] and suggested that the upper body contributes to the javelin throw, based on mean intra-group differences in several kinematic parameters between male and female finalists. Campos, Brizuela, Ramon, & Gámez [12] conducted a study comparing kinetic analysis with 3D photogrammetric technique to compare the differences between Spanish and world elite throwers. The results showed statistically significant differences between the competitors in 11 of the 35 kinematic variables (about 35%), in the last stages of throwing. Differences showed that those throwers belonging to a world-class group had a higher ability to use body strength for the speed of ejection of javelins than the Spanish, which had some technical disadvantages. This research was also realized bearing in mind the foregoing regarding the somatotype, biomechanical parameters that affect the resultant performance, as well as the possible differences between male and female throwers that occur in the structure of movement and the difference between elite javelin throwers. The main objective of the study was to determine the spatial and temporal differences of kinematic parameters in the javelin throw among male and female finalists of WC in Berlin in 2009 and WC in Daegu in 2011.

2. Method

The sample included 32 top javelin throwers (16 men and 16 women) who competed in the 2009 World Championship finals in Berlin, average result (small 83.50m and female 64.24m) and in Daegu in 2011 with average result (small 83.67 and female 65.55m). Variables were identified for estimating of biomechanical parameters.

1. Release velocity (m/s)
2. Angle of release (°)
3. Angle of attitude (°)
4. Angle of yew (°)
5. Length of impulse stride (m)
6. Length of delivery stride (m)
7. Distance to foul line (m)
8. Duration of impulse stride (ms)
9. Duration of delivery stride (ms)
10. Duration to release (ms)

Table 1a. Parameters of kinematics male and female finalist WCh (Berlin, 2009 [21])

Male athletics	Results (m)	Release velocity (m/s)	Angle of release (°)	Angle of attitude (°)	Angle of yew (°)	Length of impulse stride (m)	Length of delivery stride (m)	Distance to foul line (m)	Duration of impulse stride (ms)	Duration of delivery stride (ms)	Duration to release (ms)
A. Thorkildsen (NOR)	89,59	29,3	37,6	37,9	10,5	2,36	1,75	2,70	320	160	100
G. Martinez (CUB)	86,41	29,7	36,5	40,6	7,4	2,26	2,02	3,30	340	220	100
Y. Murakami (JPN)	82,97	28,9	31,9	34,1	11,6	2,45	1,75	2,90	300	200	80
V. Vasilevskis (LAT)	82,37	29,9	31,3	35,9	8,6	2,37	2,09	1,20	320	160	100
T. Pitkämäki (FIN)	81,90	28,9	34,3	42,7	13,3	2,24	1,93	3,50	260	200	100
A. Ruuskanen (FIN)	81,87	29,0	32,6	32,3	4,9	2,15	2,16	2,70	260	200	100
A. Kovals (LAT)	81,54	29,4	30,0	35,5	11,5	1,97	1,84	3,00	260	200	120
M. Frank (GER)	81,32	29,0	34,4	38,3	6,6	2,28	2,21	3,20	240	240	100
Female athletics											
S. Nerius (GER)	67,30	25,6	33,6	40,5	12,2	1,81	1,49	1,90	260	180	100
B. Spotakova (CZE)	66,42	25,0	38,8	44,7	13,4	1,73	1,89	3,00	220	220	100
M.Abakumova (RUS)	66,06	26,1	36,3	43,9	10,8	2,11	1,74	2,90	260	180	120
M. Stoian (ROM)	64,51	24,9	33,5	37,4	10,8	1,52	1,78	1,50	200	220	120
C. Obergföll (GER)	63,02	25,8	33,7	35,2	8,0	1,92	1,93	2,30	220	180	120
L. Stahl (GER)	63,23	24,6	33,9	40,2	10,0	2,09	1,65	1,68	260	200	120
O. Menendez (CUB)	63,11	25,7	33,9	41,1	8,4	1,86	1,98	1,40	260	240	120
S. Lika (GER)	60,29	24,3	33,2	35,4	10,9	1,99	1,48	1,40	280	200	100

Table 1b. Parameters of kinematics male and female finalist WCh, 2011(Daegu [22])

Male athletics	Results (m)	Release velocity (m/s)	Angle of release (°)	Angle of attitude (°)	Angle of yew (°)	Length of impulse stride (m)	Length of delivery stride (m)	Distance to foul line (m)	Duration of impulse stride (ms)	Duration of delivery stride (ms)	Duration to release (ms)
M.de Zordo (GER)	86,27	29,90	37,3	40,3	3,0	1,96	1,71	1,40	366	253	140
A. Thorkildsen (NOR)	84,78	28,62	35,9	39,2	3,3	2,39	1,89	1,84	400	170	107
G. Martinez (CUB)	84,30	28,33	36,7	35,7	1,8	2,51	1,99	1,45	443	243	124
V.Vesely (CZE)	84,11	26,79	34,6	39,9	5,3	1,92	1,83	0,85	320	180	120
F. Avan (TUR)	83,34	27,44	31,5	35,2	3,7	2,06	1,66	1,07	323	197	163
R. Avramenko (UKR)	82,51	27,93	34,2	41,5	7,3	2,53	1,58	0,65	374	183	137
J. Bannister (AUS)	82,25	27,11	31,5	31,2	0,3	2,39	1,61	0,37	427	193	143
M. Frank (GER)	81,81	27,04	35,2	35,8	0,6	2,13	1,87	1,88	374	213	143
Female athletics											
M. Abakumova (RUS)	71,99	25,11	39,4	43,8	4,4	1,87	1,74	2,36	313	194	140
B. Spotakova (CZE)	71,58	26,27	38,2	42,2	4,0	1,61	1,60	2,54	313	190	147
S.Viljoen (RSA)	68,38	24,42	39,3	43,0	3,7	1,59	1,41	1,66	310	167	113
C.Obergfoll (GER)	65,24	26,48	33,2	35,2	2,0	2,10	1,66	1,20	370	173	143
K. Molitor (GER)	64,32	26,09	38,8	41,3	2,5	1,91	1,51	0,57	433	203	154
K. Mickle (AUS)	61,96	25,10	38,9	43,9	5,0	1,81	1,74	1,91	350	203	130
M. Ratej (SLO)	61,65	27,49	37,3	32,3	5,0	2,51	1,51	1,64	450	164	133
J. Klimesova (CZE)	59,27	24,96	38,6	41,7	3,1	1,66	1,10	1,85	257	287	143

3. Results

Table 2. Differences of kinematic parameters finalists men (T-test independent samples)

The kinematic parameters	World Championship	Mean±Std.Dev.	t-value	p<Sig. (2-tailed) **0,001; *0,005;
Release velocity (m/s)	Berlin	29,26±0,38	3,504	0,004**
	Daegu	27,90±1,04		
Angle of release (°)	Berlin	33,57±2,61	-0,864	0,402
	Daegu	34,61±2,18		
Angle of attitude (°)	Berlin	37,16±3,42	-0,109	0,915
	Daegu	37,35±3,45		
Angle of yew (°)	Berlin	9,30±2,89	4,664	0,000**
	Daegu	3,16±2,35		
Length of impulse stride (m)	Berlin	2,26±0,15	0,233	0,819
	Daegu	2,24±0,25		
Length of delivery stride (m)	Berlin	1,97±0,18	2,444	0,028*
	Daegu	1,77±0,15		
Distance to foul line (m)	Berlin	2,81±0,71	5,120	0,000**
	Daegu	1,19±0,55		
Duration of impulse stride (ms)	Berlin	287,50±36,94	-4,462	0,001**
	Daegu	378,38±44,20		
Duration of delivery stride (ms)	Berlin	197,50±27,12	-0,454	0,657
	Daegu	204,00±30,11		
Duration to release (ms)	Berlin	100,00±10,69	-4,837	0,000**
	Daegu	134,63±17,20		

Abbreviation: Mean (average value), standard deviation (St.Dev), coefficient of t-test value (T-value), significance level p (Sig. * p<0,005; Sig. **p<0,001).

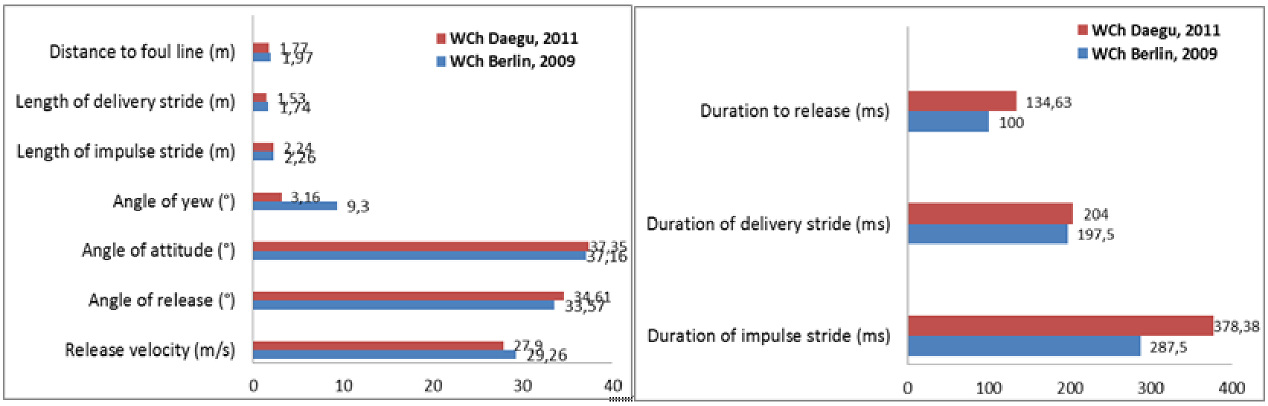

Figure 1. Mean values of kinematic parameters male finalist World Championships

Inspection of Table 2 found 60% of statistically significant differences between the male finalists in Berlin and Daegu. Differences were observed in six out of ten parameters, namely in the speed of ejection (T=3,504; p<0,004), the angle of diversion (T=4,664; p<0,000), the length of the step provided (T=2,444; p<0,028), distances to line (T=5.120; p<0.000), duration of ejection (T=-4,837; p<0,000), and impulse step duration (T=-4,462; p<0,001).

The average ejection velocity of male finalists in Berlin was quite homogeneous (29,26m/s), which is 1.36m/s faster than the finalists from Daegu (Table 2). A relatively large average bounce angle (33,57°) was also observed, preceded by a short duration of the impulse step (288ms) and the stretched step (198ms), performed at the average length of the impulse step (2,26m) and the stretched step (1,97m), (Table 2, Figure 1). Japanese thrower Murakami achieved the maximum impulse stride length (2,45m) in the final in Berlin, and German thrower Frank (2,21m) was the last placed. The average length of the finalists' ejection from Berlin is also quite homogeneous (100ms) and much shorter than the Daegu finalists.

Comparing the kinematic parameters of the finalists, it is evident that the 2011 Daegu finalists had a lower ejection velocity (27,90m/s) and a higher ejection angle (34,61°). The length of the impulse and stretched step was several inches greater for the finalists in Berlin (1,97m) than in Daegu (1,77m), while the duration of the impulse and stretched step as well as the ejection phase was longer in Daegu than in Berlin (135ms). The average distance to the ejection line in Daegu (1,19m), in Berlin (2,81m) can be explained by the mental state of the competitor, greater fear of a possible transgression, and thus a poorer result (Table 2, Figure 1). The longest impulsive step in Daegu was achieved by Ukrainian Avramenko (2,53m), and the stretched step (1,99m) by third-placed Cuban competitor Martinez (Table 1a). The Berlin finalists achieved, on average, a higher turning angle (9,30°) and shorter pulse duration (287ms). There is an inverse relationship between the speed of ejection and the angle of ejection in both finals, which is characteristic of all throwing disciplines. In the end, the average result was better in the Daegu final than in Berlin by 17cm.

Table 3. Differences of kinematic parameters finalists women (T-test independent samples)

The kinematic parameters	World Championship	Mean±Std.Dev.	T-value	p<Sig.(2-tailed) **0,001; *0,005;
Release velocity (m/s)	Berlin	25,25±0,64	-1,158	0,266
	Daegu	25,74±1,01		
Angle of release (°)	Berlin	34,61±1,95	-3,365	0,005*
	Daegu	37,96±2,04		
Angle of attitude (°)	Berlin	39,80±3,57	-0,316	0,756
	Daegu	40,42±4,29		
Angle of yew (°)	Berlin	10,56±1,79	9,182	0,000**
	Daegu	3,71±1,11		
Length of impulse stride (m)	Berlin	1,88±0,20	-0,029	0,977
	Daegu	1,88±0,31		
Length of delivery stride (m)	Berlin	1,74±0,19	2,077	0,057
	Daegu	1,53±0,21		
Distance to foul line (m)	Berlin	2,01±0,65	0,919	0,374
	Daegu	1,72±0,63		
Duration of impulse stride (ms)	Berlin	245,00±27,77	-4,140	0,001**
	Daegu	349,50±65,76		
Duration of delivery stride (ms)	Berlin	202,50±22,52	0,305	0,765
	Daegu	197,63±39,26		
Duration to release (ms)	Berlin	112,50±10,35	-4,409	0,001**
	Daegu	137,88±12,56		

Abbreviation: Mean (average value), standard deviation (St.Dev), coefficient of t-test value (T-value), significance level p (Sig.* p<0,005; Sig. **p<0,001).

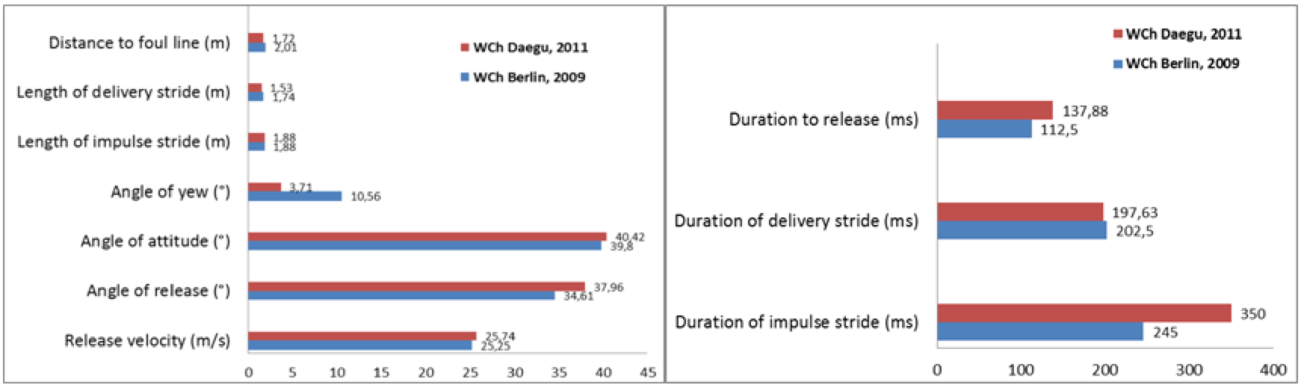

Figure 2. Mean values of kinematic parameters male finalist World Championships

Analysing the results of the female finalists, 40% of statistically significant differences were observed. Differences were recorded in the ejection angle (T=-3,365; p<0,005), the diversion angle (T=9,182; p<0.000); duration of impulse step (T=-4,140, p<0.001) and duration of ejection (T=-4,409; p<0,001). Compared to the finalists from Berlin in 2009 in Daegu achieved a lower average score (64,24m). The finalists in Berlin also achieved a lower ejection rate (25,25m/s), a smaller ejection angle (34,61°), but a larger spear angle by about 7°. It is interesting to note that the average stride length of 1,88m as well as the angle of stance was almost identical in both finals, with the length of stride being longer in Berlin (1,74m) than in Daegu (1,53m). The distance from which they ejected from the throwing line was 29cm shorter in Berlin (Table 3, Figure 2). Compared to the men's finalists in Berlin, women threw a lower average throwing speed of nearly 5m/s (25,25m/s). However, they achieved a higher average bounce angle (34,61°), preceded by a slightly longer impulsive step (1,88m) of 245ms and a stretched step (1,74m) of 203ms. The maximum length of the impulse step was achieved by Maria Abakumova (2,11m) and the stretched step by Cuban Osleidis Menendez (1,98m). The average duration of the ejection is quite homogeneous and amounted to 112,5ms. What made women more successful than the male finalists was the distance to the ejection line, for men it was a distance of 2,81m and for women it was 2,01m which is a precondition for a good result. Other parameters were also variable, which was largely dependent on the throwing technique. It often happens that the same competitors in different competitions produce different results that are significantly weaker or better than previous results. These findings can be confirmed by analysing the differences of the same athletes in different competitions. For example first place from Berlin and second place in Daegu (Spotakova) and first place in Daegu and second place in Berlin (Abakumova) who achieved a smaller result by almost 5m in two different championships. Other kinematic parameters also noted significant differences, confirming the unwritten rule that one athlete cannot achieve the same result twice and with the same biomechanical parameters.

4. Discussion

The main objective of the study was to record and determine statistically significant differences in kinematic parameters between Berlin WCh and Daegu WCh finalists. The results confirmed the differences in measured parameters between the two world championships in the men's and women's finals. In men, 60% differences were observed (release velocity, angle of yew, length of delivery stride, distance to foul line, duration of impulse stride, duration to release), unlike in women where differences in 40% of kinematic parameters (angle of release, angle of yew, duration of impulse stride, duration to release) were observed. It can be concluded that these differences within the same gender are present due to different technical performance, technical performance, different somatotypes, mental state in the final of the competition, training process, aerodynamic device path, pace of rhythm, etc.

The technical performance of javelin throwing is very important, where even small deviations from the proper technique shorten the length of the throw but also have a very bad effect on the wrists, ligaments and tendons of the competitor. Javelin throwing is a combined form of movement, in which the thrower seeks to produce the greatest possible acceleration at the moment of ejection through the combined perpendicular-cyclic and rotational-acyclic movement of the body to achieve the maximum flight distance, as confirmed by this research. The average ejection velocity for male finalists is about 29m/s, for women 25m/s, with higher individual competitor values recorded (Vasilevskis, Thorkildsen, Martinez, Zordo, Kovals, Abakumova, Nerius, Spotakova, Obergfoll, Molitor). Throwing a javelin requires a sharp kinaesthetic feel in handling the device and a special explosiveness at the moment of ejection. Contrary to the view that this is a simple arm throwing, this discipline utilizes whole-body activity, which involves the participation of strength and speed-power, coordination and especially flexibility. Also, the speed of take-off is of great importance for achieving the maximum possible initial speed of ejection of the device. For elite male throwers, the speed of movement at the end of the first part of the run is over 8m/s, or 6-7m/s for female throwers, taking care to match the optimal running speed with the technique of performing movement in the phase of overtaking the device [1]. In order to realize such high initial velocities, it is evident that the throwing disciplines also require a large amount of force produced over a short period of time. Due to easier gear, the speed of ejection plays a bigger role in throwing a javelin than other throws (shot put, discus, and hammer), so it is significantly higher than other throws. For elite javelin throwers, it goes well over 30m/s, with mere ejection duration of 0,16-0,18 sec [13,14]. Maximizing the ejection velocity gives athletes the highest chance of achieving a good result, which is in line with the results of this study, where the first-ranked competitors in both finals had an ejection rate of about 30m/s at 80ms-120ms. Some authors [5] consider that elite launchers have been developing as much as 70% of the ejection rate in the last 0.1sec. This speaks to the importance of the speed of force exertion, i.e. athletes should train and during the training process develop ways of how to produce the greatest amount of force in the shortest time. According to the study [1], the javelin was found to have the lowest value of the force action on the device in the ejection phase due to the least weight (about 350N) at the ejection duration of 0.1sec, which was absolutely confirmed in this study.

Compared with the results of this study, javelin throwers during the fifth WC in Gothenburg in 1995, had a lower average ejection velocity (28,78m/s), a higher ejection angle (38°), and a smaller deflection angle (7°). As it has been pointed out, the speed of the ejection plays a more important role than in other throwing disciplines, was confirmed by the first-ranked Jan Zelezny and the angle of 40° at the speed of 30.2m/s. Although the runner-up had a greater height of ejection (by 21cm), he still ruled a good ejection angle with the highest ejection rate. Even today's elite spear throwers are aiming for a maximum ejection angle of almost 40° at maximum speed. It is taken into account that the angle of ejection of the javelin between the direction of movement of the javelin and the horizontal is 29º-36º and represents the individuality of the thrower. The average angle of ejection of the male finalists at the 2009 World Cup in Berlin was about 34° (Thorkildsen-37,6°) with an average ejection velocity of almost 30m/s (Vasilevskis-29,9m/s). In Daegu, the average ejection angle was 34,6º (de Zordo-37,3º) and the average ejection velocity was 28m/s (de Zordo-29,90m/s). For top pitchers, the length of the kickback path ranges from 210-250cm and the maximum stress time interval is 0,12-0,18sec. at a discharge angle of 27º-40º, which is also consistent with the results of this study.

According to [15], the speed of ejection of the javelin is not achieved by the maximum force exerted, such as in a shot put, discus and hammer, but by bringing the body to the best anatomic-biomechanical position to make the most of the neuromuscular and biomechanical potentials. This is primarily related to the significant utilization of the body's natural mechanisms to improve the stretching reflex and the stretching cycle of actual muscles. It is an involuntary reflex response, when contraction speed is often faster and more powerful than completely voluntary muscle contraction. Physiologically speaking, the faster the muscle eccentrically stretches, the greater the force of the next concentric contraction, as any tension developed in the musculoskeletal joint by eccentric muscle loading causes it to act in a similar manner to a spring. When this stored energy is released, it helps to increase the strength of the next concentric contraction [16]. In this connection, these neuromuscular activities are of great importance for the preparations of javelin thrower. Electro-myographic studies have shown that, in a strained javelin arch, the muscular extensors of the torso, extensors and flexors of the hip joint, the anterior muscles of the torso, chest and shoulder girdle bear the greatest strain. However, the highest activity is indicated by the clavicular and lumbar-rib parts of the muscle, while electrical activity has not been established in the abdominal part [1].

In order to maximize the maximal rate of ejection, two neuromuscular strategies are crucial, namely the strategy of close-range ejection and the active acceleration-stopping of body segments. Ejection from a still position into the distance has proven to be the best pattern for increasing the ejection rate. In this case, the stronger muscles of the proximal joints (near the torso) are activated before the weaker but faster, more distant joints, taking advantage of the impulse of each joint and generating the force of an athlete who throws primarily with leg extension, rotation and flexion of the torso. The actions of these proximal joints account for more than 50% of the force in the standing posture and increase when the ejection is preceded by a run-in approach, such as in the case of a javelin throw, the so-called crossover steps [17]. The crossover step is a low jump that connects the run-in with the maximum acceleration phase and depends on its proper execution of the velocity gained in the run-up. Such rapid momentum gives the pelvis and legs additional acceleration allowing the legs to reach the upper torso. The length of this step is individual (from 190-255cm) in the thrower but shorter than the previous ones in overtaking the device. A well and properly executed crossover step allows good entry into the so-called ejection position, which is a key position when performing shots [1].

Another feature of effective movement coordination in javelin throwing is the continuous acceleration and stopping of major body segments. Competitors first achieve an initial acceleration of the competitor-javelin system in the first part of the run-in, and as they approach the ejection point there is a sudden slowdown of body parts from the ground upwards (from the stop leg to the ejection arm). When done well, it allows the athlete to achieve far higher ejection rates than would be the case if he did not use this sequence of runs, i.e. acceleration and deceleration, the so-called reactive transmission of momentum. This movement strategy helps transfer momentum from the lower extremity to the upper, from the upper extremity to the jaw [18-20]. This sequence of movements creates a whip-like movement that implies the rapid movement of the proximal joints in the sagittal plane in the direction of throwing, and then their abrupt stopping, as confirmed by the results [8]. This is done in the fifth step by placing the extended left foot with the heel in front of the body with an inhibitory effect (resistance) in the distance of 150-220cm. This relationship was confirmed in the current survey of finalists (Berlin-Daegu), and significant differences were also observed between men, while women had the same average length of step (1.88m). In the maximum effort phase, the pitcher takes the position (inclination) of the longitudinal axis backwards relative to the substrate by about 60º. This phase contains several continuous stresses in which the maximal engagement of the central and lower regions of the body relative to the maximal activation of the shoulder girdle and arms has a spatial and temporal advantage. Particularly important is the work of the left leg in the last throwing step, which is highly inhibitory, allowing the action of inertial forces, as the body wants to maintain its previous speed. In this case, the inertial forces will be larger if the pelvic-thigh braking is more pronounced. Accordingly, it enables more active stretching of the muscles active in the throwing and lowering of the movement of the upper body, and thus contributes to the acceleration of the javelin in the last phase of maximum acceleration, which is in accordance with the results of research [11]. It is important that the foot of the left leg should be lowered as quickly as possible after the right foot and firmly placed on the ground to the left of the throwing line. Resisting the left leg eliminates the possibility of directing one part of the force during ejection outside the javelin, controlling the movement of the left hip and blocking the left side of the body. With the left leg positioned, the pitcher is in a two-prong support, with a pronounced tilt of the longitudinal axis of the body towards the back (and more than 60º) to the right. The lower part of the body represents the handle of the whip, and the upper part of the body, through the right hand carrying the javelin, the whip itself. The level of quality of each thrower's technique depends on mechanical principles that are consistent with his motor-functional abilities and morphological dimensions [1]. Certain dynamometric and kinematic analyses also showed a high correlation of left foot inhibitory activity with sports performance. The angle of placement of the left foot on the ground at top throwers (160º-165º) must have a strong support (load reaches about 350kg) in order for the torque of the leg on which it rests to be effectively used. For the whole activity of ejecting the javelin and achieving optimum acceleration, the relevant parameters, the length of the trip and the time of its execution, the angle and height of the ejection are relevant.

The aerodynamic force, although not the subject of this research, is very influential on the results of the throwing of the javelin, which is the product of the interaction of the javelin and the air current. This aerodynamic force is decomposed into two forces. One acts opposite to the direction of movement of the javelin and produces a drag force, while the other maintains the javelin to fly in the air and makes a buoyancy force. During flight, the javelin rotates about the longitudinal axis due to the effect of aerodynamic force in the centre of pressure rather than in the centre of gravity of the javelin, so that air flow acts over its entire surface. Also, the weather conditions of the competition condition the manifestation of aerodynamic force as well as certain kinematic parameters that more or less contribute to the overall result.

Generally speaking, this research showed that significant differences were observed between male finalists and between female finalists. Mostly, these are kinematic parameters that have proven to be paramount in the resultant performance of these championship throwers. One should not forget the influence of exogenous factors, above all the air currents and the behaviour of the javelin as an aerodynamic device. Based on the differences in the kinematic parameters of the top medal winners at the Berlin WC in 2009 and the Daegu WC in 2011, an ideal biomechanical model of the thrower can be made.

5. Conclusion

The study was conducted on a sample of 32 finalists at the 2009 World Athletics Championships in Berlin and Daegu in 2011 with the aim of determining the differences between the kinematic parameters of the men's and women's javelin throwers. The sample included a total of 32 competitors in both categories. The results of the study confirmed statistically significant differences between male finalists in 60% of kinematic parameters: release velocity (t=3,504; p<0,004), angle of yew (t=4,664;

p<0,000), length of delivery stride (t=2,444; p<0,028), distance to foul line (t=5,120), duration of impulse stride (t=-4,462; p<0,001), duration to release (t=-4,837; p<0,000). In women, significant differences in 40% of parameters were confirmed: angle of release (t=-3,365; p<0,005), angle of yew (t=9,182; p<0,000), duration of impulse stride (t=-4,140; p<0,001), duration to release (t=-4,409; p<0,001).

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Pavlovic, R. Athletics. 2016, Niš. Association of writers Branko Miljkovic.

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

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

[4] Gregor, R., & Pink, M. Biomechanical Analysis of a World Record Javelin Throw: A Case Study. *Journal of Applied Biomechanics* 1985; 1 (1): 73-77.

[5] Morriss, C., & Bartlett, R. (1996). Biomechanical Factors Critical for Performance in the Men's Javelin Throw. *Sports Medicine*, 1996; 21, (6): 438-446.

[6] Whiting, W.C., Gregor, R.J, & Halushka, M. Body Segment and Release Parameter Contributions to New-Rules Javelin Throwing. *Journal of Applied Biomechanics*, 1991; 7(2): 111-124.

[7] Murakami, M., Tanabe,S., Ishikawa,M., Isolehto, J., Komi,P., & Ito, A. Biomechanical analysis of the javelin at the 2005 IAAF World Championships in Athletics. *IAAF*, 2006; 21:2; 67-80.

[8] Murakami, M., Tanabe, S., Ishikawa, M., & Ito, A. The Relationship between Approach Run Kinematics and Javelin Throwing Performance. *Asian Journal of Coaching Science*, 2017; 1 (1): 1-14 (December, 2017).

[9] Liu, H., Leigh, S., & Yu, B. Sequences of upper and lower extremity motions in javelin throwing. *Journal of Sport Sciences*, 2010; 28 (13): 1459-1467.

[10] Bartlett, R.M., Mueller,E., Lindinger,S., Brunner,F., & Morris,C. Three dimensional evaluation of the kinematic release parameters for javelin throwers of different skill level. *Journal of Applied Biomechanics*, 1996; 12(1): 58-71

[11] Mero, A., Komi, P., Korjus, T., Navarro, E., & Gregor, R.J. Body segment contributions to javelin throwing during final thrust phases. *Journal of Applied Biomechanics*; 1994; 10(2), 166-177.

[12] Campos, J., Brizuela, G., Ramon, V., & Gámez, J. Analysis of kinematic parameters between spanish and World class javelin throwers. 20 International Symposium on Biomechanics in Sports. ISBS 2002, Caceres - Extremadura – Spain

[13] Zatsiorsky, V.M. *Science and Practice of Strength Training*. 1995; (1st ed.). Champaign, IL: Human Kinetics.

[14] Bartonietz, K. Javelin Throwing: an Approach to Performance Development. 2000; In V. Zatsiorsky (Ed.), *Biomechanics in Sport* (pp. 401-434). London: Blackwell Science Ltd.

[15] Young, M. Preparing for the Specific Neuromuscular and Biomechanical Demands of the Javelin Throw , 2007; Available at http://citeseerx.ist.psu.edu/viewdoc/similar?doi=10.1.1.532.6962&type=ab.

[16] Komi, P.V. *Stretch-shortening cycle*. In P.V. Komi (Ed.). Strength and Power in Sport.1992; (pp.169-179). Blackwell Scientific Publications: Oxford

[17] Coleman, A.E. *A Baseball Conditioning Program for all Seasons*. In: Injuries in Baseball.1988; (pp. 537-545). Philadelphia, PA: Lipincott-Raven Publishers.

[18] Kearney, J.K., Bath, D., Prasad, B., & Yuan, S. *Efficient generation of whip-like throwing and striking motions.* In N. Thalmann Magnenat & D. Thalmann (Eds.), Models and Techniques in Computer Animation, 1993; (pp. 270 284). Tokyo: Springer Verlag

[19] Bath, D.N, & Kearney, J.K. On animating whip-type motion. *Journal of Visualization and Computer Animation*, 1996; (7): 229-249.

[20] LeBlanc, M.K., & Dapena, J. Generation and transfer of angular momentum in the javelin throw. Presented at the *20th Annual Meeting of the American Society of Biomechanics.* Atlanta, Georgia. 1996; October 17-19.

[21] Mendoza, L., Nixdorf, E., Isele, R., & Gűnther, C. Biomechanical Analysis of the Javelin throw Men and Women Final. 2009. *Scientific Research Project Biomechanical Analyses at the 12 IAAF World Championship, Berlin, 2009 Final Report Javelin Throw.*

[22] Yoon, C.J., Lee, H.S., Kim, J.W. et al. Biomechanical Analysis of the Javelin Throw Men and Women Final. 2011. *Scientific Research Project Biomechanical Analyses at the 13 IAAF World Championship, Daeegu, 2011 Final Report Javelin Throw.*