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The Differences of Kinematic Parameters Triple Jump Between Finalists WCH Berlin, 2009 – WCH Daegu, 2011

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Abstract

Kinematic parameters often crucially influence the performance in athletic disciplines. This is especially evident for top athletes who have almost identical morphological, motor and functional parameters. The differences that affect the sporting result are generally attributed to a better performance technique that is often the consequence of the different values of the individual's kinematic parameters. This study analyzes the differences between the defined kinematic parameters in the discipline triple jump. The sample included 16 male athletes who competed in the finals of the World Championships (Berlin, 2009; Daegu, 2011) and a total of 22 kinematic parameters were selected. The results were obtained by applying the T-test module for small independent samples, confirming the differences between women's finalists in Berlin and Daegu. Statistically significant differences were recorded only in five out of 22 kinematic parameters (23 %). Statistically significant differences were achieved in the rebound angle of hopping (Hop°, T = 3,689; p<0.003); vertical speed of hopping (VVo Hop m/s, T = 5,269; p < 0,000), contact phase duration of hop (T = -3,580; p < 0.003), step (T = -5,193; p < 0,000), jump (T = -1,966; p < 0,071), it is also evident that athletes in Berlin had, on average, shorter time of contact phase in all three parameters (hop, step, jump). An inverse relationship between the speed and the angle of rebounding of the competitors was noticed in both finals, which is a consequence of the speed reduction in each jump, where athletes use a greater swing with free extremities.

Keywords: athletes, World Championship, triple jump, kinematic parameters, differences.

1. Introduction

Triple jump is an acyclic-cyclic movement in structure, and a very demanding and complex athletic discipline characterized by a very high unity of motor skills and abilities (speed, explosive power, coordination, flexibility, balance) that are precisely crucial for successful performance. It is the only jumping discipline that does not require a large explosive effort, but it represents a continuous series of movements, in which each phase depends on the previously performed phase (Jovović, 2006; Schiffer, 2011, Pavlović, 2016). Although each segment of the triple jump can be isolated, it is important that the head has the total activity. During the performance of the triple jump, the synergic effect of the latent and manifest motor space of each triple jumper is very clearly demonstrated. Fatal knowledge and motor abilities (speed-strong abilities, specific forms of endurance, flexibility) jointly define the end result of a triple jump but with a slightly higher motor-endurance result in the end result. No matter how the technique of triple jump is ideal, athletes

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cannot count on top results in this discipline if the listed abilities are not at the required level, and that is top level (Idrizović et al., 2015). Performance in the triple jump is a quantitative expression of factors of both primary and secondary importance. The mastering of a rational and effective technique is a precondition for the greatest realisation of the motor potential of a particular jumper (Miladinov, Bonov, 2004).

To be successful, triple jumpers must possess above average sprint and jumping abilities while at the same time they must have strong muscularity and motor skills (Hayes, 2000). Kreyer (1982) states that the elite triple jumpers of the time achieve the best time at 100m in the interval between 10.4s and 10.7s using a running start of 42-50 m, which depends on their achievements, the acceleration ability and frequency of the step. As with other jumping disciplines, the height of the hips in the rebound affects the efficiency and length of each subsequent phase, i.e. if the hips are higher the amplitude of the flight is higher. The angle under which the hips begin to fly must be as low as possible (below 16°), because through the next phases of the step and the jump the velocity disappears, and the angle of reflection increases automatically, i.e. its explosive power increases with the decrease of the jumper's speed (Schiffer, 2011). The angle of reflection in hopping, stepping and jumping is an individual matter and depends on the morphological, motor dimensions, as well as the control of the triple jump technique, which depends on the modified technique that is applied. With today's top jumpers, the angle of reflection in the hopping phase is from 13°-16°, in the stepping 12°-16°, and in the jumping phase it is 18°-26°. The relationship of these angles with the speed of motion is not linear, but inverse, i.e. with each jump of jumper the speed of movement decreases, and the reflection angle and swing of extremities increases (Pavlović, 2016). The shorter the depreciation and the earlier start of the spring, the body of the jumper moves in a new direction and therefore there is the greater angle of movement.

Since the triple jump is performed in the sagittal level during all jump-phases, there is a disturbance of the equilibrium position, due to the front rotations, unequal work of the hands or landing with incorrectly positioning of the feet (Miller, Hay, 1986). In an attempt to achieve maximum lengths of hopping and stepping, sometimes the jumper dips well in front of the projection of the hips, increasing the reaction of the pad (Rp) and thus interrupts the sequence of the movements (Idrizović, 2010). In order to reduce this effect, the foot and the pad contact must be slightly ahead of the TT projection (hips). This contact requires patience, waiting for the ground to be beneath the leg, and not reaching the ground with the leg. The contact between the feet and pad should be as short as possible, i.e. it must be reflected as soon as possible, and the best way to achieve this is to think of a hopping (I jump - 0,11-0,12sec.) and stepping (II jump - 0,13-0,15 sec.) in terms of reflection, and not on the landing (III jump-0,17-0,19sec) (Jovović, 2006; Pavlović, 2016).

During the rebound, the jumper acts with great forces on the pad, which are manifested in a very short time. In the reflection, certain parts of the locomotor apparatus and in particular the spinal column, suffers from loads that are 4-6 times the weight of the jumper himself. At the moment of reflection that lasts from 0.11 to 0.13 sec. The jumper develops an effort of an average of up to 500 kg (Jovović, 2006; Pavlović, 2016). Regardless to the high technique of athletes, he/she cannot count on top results if he/she does not have a high level of motor skills (all forms of speed, strength, coordination, flexibility). The speed of the triple jumpers from the running start to the landing is relatively large with an average time of about 10 m/s and a tendency of speed falling, which is individual. According to some authors (Jovović, 2006; Idrizović, 2010; Schiffer, 2011; Stanković, & Raković, 2010; Pavlović, 2016), the great influence on the length of the jump has achieved the horizontal velocity during the running start (horizontal component) and the vertical velocity of the bouncing (vertical component) with each reflection and triple jump technique as a whole. This ratio is 3:1, which implies a high speed of running start and a small angle of reflection. The average length of the jumps of today's triple jumpers is 36-38 % - 29-30 % - 33-35 % (Mihajlović, 2010), with the note that there are individual differences among jumpers, where the hopping length is 34-38 %, stepping 28-33 % and jumping 32-34 % (Pavlović, 2016). The mean phase distribution was 36,5 %, 29,3 % and 34,2 % for the hop, the step and the jump respectively (Panoutsakopoulos, Kollias, 2008). The observed phase distribution was similar to that observed in contemporary top competitions (i.e. 2005 WCh in athletics: 36,2 %-29,4 %-34,5 %).

This percentage of the men's finals in Berlin in 2009 was at Idowu (36-30-34%), Evore (37-31-32 %), Copella (34-33-33 %), Taylor (34-29- 37 %), Olson (37-29-34 %), Clayea (33-31-36 %).

These percentage differences in the length of the jumps are conditioned, in addition to the psychosomatic and motor potential of the jumper, by the technique of performing (the hopping is dominant, the jump is dominant or even technique). According to some authors, Jonathan Edwards, the world record holder with 18,29m, had a percentage ratio of jumps (33,10 - 28,50 - 38,40 %) at the time of the record, which was the highest percentage in the third jump compared to the previous record holders. His horizontal acceleration in hopping was 9.48m/s, in stepping 8.39m/s and in jumping 7.20m/s. As a consequence of the decrease in horizontal acceleration, a reflection angle (16-14.5-19°) has been increased, confirming the allegations (Schiffer, 2011; Pavlović, 2016) about the inverse relationship of horizontal velocity and explosive power in the manifestation of hopping, stepping and jumping. Almost identical relationship of these parameters was recorded at B.Wellman (14-17-22°) and P. Idowu (14-13-21°) (Mendoza et al., 2009). They also have a horizontal speed decreasing in each segment of the jump and a reflection angle increasing, which is a confirmation of the inverse relationship of these two kinematic parameters (Hay, 1994; 1997; Yu, 1999). In the triple jump discipline, the explosive power of the jumping type and technical potentials have a significantly higher impact on the end result in triple jump than in the long jump, where there is a positive but not high correlation (r=0,58). However, the research (Panoutsakopoulos, Kollias, 2008) confirms a strong, positive and higher correlation between the speed of the running start and the triple jump (r=0,81). According to some indicators (Hutt, 1989), at a running speed of 10.50m/s in the last 6 meters the predicted result is 17,50m, while for the running speed of 9,40m/s, the predicted result is 14.50m. How important is the speed of the running start in the result performance can be seen in the results of the triple jump recorders. The running start speed in Göteborg of J.Edwards (18.29m) from 11-6m was 9,80m/s, and from 6-1m was 11,90m/s. The same section the recorder Y.Savigne (14,95m) from 11-6m ran at a speed of 9,20m/s, and from 6-1m at a speed of 9,36m/s (Mendoza et al., 2009). It is known that different speeds in running start also give different lengths of long jumps. According to Osolin (2001), it is generally known that an acceleration of 10,0m/s gives a 8m jump length, an acceleration of 9m/s gives 7m, and an acceleration of 8m/s is a score of 6m and the triple jumps should not be higher, and all in the domain of physical and mental possibilities, conative and cognitive characteristics of the contestants (Pavlović et al., 2016). That this fact can be accepted as true is confirmed in the research conducted by Pavlović, Idrizović, Kinov, Joksimović, 2016, who analyzed the differences in the kinematic parameters between the women's finalists in the long jump championships in Berlin, 2009 and in Daegu, 2011. Of all the measured kinematic parameters, the obtained results confirmed the statistically significant differences only at the speed of the second step ($p < 0.05$), while other parameters were not statistically significant. In the case of differences in kinematic parameters between different sexes, then the differences are evident, which was expected and confirmed by the research of Pavlović, Bonacin, Stanković, 2016. They analyzed the differences in the male and female finalists of the World Athletics Championship in Berlin in 2009 in long jumps in order to determine the differences in kinematic parameters. The obtained results confirmed the significant differences between male and female athletes, where 72 % of the analyzed differences in kinematic parameters were in favor of male jumpers. The differences were identified in the running speed of the track section 11-6m and 6-1m, the speed of the second and the first step, and the horizontal impulse rate for the level of significance ($p < 0.001$). Also, the differences in the parameters of the lengths of the third and first steps as well as the vertical velocity of the significance level ($p < 0.05$) were identified. Identical to the long jump, in addition to motor and functional abilities that are quite equable, the kinematic parameters are of paramount importance for the result performance of the competitors in the triple jump. Depending on the performance of the technique, the physical preparation of a jumper, sex, age, motivation and other exogenous and endogenous factors, depend their possible differences in result performance. Mendoza, et al (2008) conducted a biomechanical analysis of triple jump competitions, of all eight male and female finalists during the VI World Athletics Championship in Stuttgart. The obtained kinematic parameters can be used to define the type of jumper, technique and the influence of kinematic parameters on the total result.

Based on the previously mentioned facts of biomechanical parameters and their relationships in the structure of jumps with emphasis on the triple jump emerged the idea of current study. The research is significant, more so, since there have not been any studies that have dealt with this problem of triple jumps, regarding the possible differences in kinematic parameters between men's finalists of the World Athletics Championships in Berlin in 2009 and Daegu in 2011. The main goal of the study is to determine statistically significant differences in the kinematic parameters between the male athlete finalists at WC in Berlin 2009 and WC in Daegu in 2011.

2. Method

The population defined in the research has included top male athletes in the Triple Jump World Championship in Berlin, 2009 (results mean: 17,28 m) and Daegu, 2011 (results mean: 17,50 m). The sample included a total of 16 finalists, who participated in the Triple Jump Final. The variables of kinematics parameters:

1. Length of 2 steps before take-off- L2SL (m);
2. Length of 1 steps before take-off - L1SL (m);
3. Length of Hop (m);
4. Length of Step (m);
5. Length of Jump (m);
6. Relative distance of Hop (Hop %);
7. Relative distance of Step (Step %);
8. Relative distance of Jump (Jump %);
9. Angle of take-off Hop (Hop°);
10. Angle of take-off Step (Hop°);
11. Angle of take-off Jump (Hop°);
12. Horizontal velocity 2 length –HVLCT 2L (m/s);
13. Horizontal velocity 1 length –HVLCT 1L (m/s);
14. Horizontal velocity Hop-HVLCT Hop (m/s);
15. Horizontal velocity Step-HVLCT Step (m/s);
16. Horizontal velocity Jump-HVLCT Jump (m/s);
17- Vertical velocity Hop –VVLCT Hop (m/s);
18. Vertical velocity Step –VVLCT Step (m/s);
19. Vertical velocity Jump –VVLCT Jump (m/s);
20. Contact of Hop (s);
21. Contact of Step (s);
22. Contact of Jump (s).

Data obtained in the survey were analyzed by standard descriptive methods, and the differences between groups of respondents-finalists were tested using Student's t-test for independent samples. Statistical analysis was done using the statistical program Statistica 6.0.

Table 1a. Parameters of kinematics men finalist WCh, 2009. Berlin (Mendoza et al. 2009)

Atletičar	Rezultat (m)	Stride length (m)					Relative distance %			(o) Angle of take-off ~ (o)		
		2 L	1 L	HOP	STEP	JUMP	HOP	STEP	JUMP	HOP	STEP	JUMP
P. Idowu	17,73	2,58	2,49	6,49	5,41	6,02	36	30	34	14	13	21
N. Evora	17,55	2,68	2,26	6,51	5,41	5,68	37	31	32	16	13	26
A. Copello	17,36	2,41	2,29	6,01	5,77	5,92	34	33	33	13	15	20
L. Sands	17,32	2,92	2,30	6,52	5,20	5,62	38	30	32	15	14	18
A. Girat	17,26	2,49	2,33	6,16	5,41	5,88	35	31	34	15	16	19
Y. Li	17,23	2,30	2,46	6,33	5,24	5,75	37	30	33	16	16	20
I. Spasovkhodsk y	16,91	2,55	2,49	6,47	4,80	5,69	38	28	34	14	13	21
J. Gregorio	16,89	2,71	2,62	6,33	5,10	5,72	37	30	33	15	12	20
Mean	17,28	2,58	2,40	6,35	5,29	5,78	36,5	30,37	33	15	14	**22**

Atletičar	Horizontal velocity (m/s)					Vertical velocity (m/s)			The Contact (s)		
	2 L	1 L	HOP	STEP	JUMP	HOP	STEP	JUMP	HOP	STEP	JUMP
P. Idowu	10,47	10,53	9,72	8,48	7,01	2,45	1,94	2,70	0,13	0,16	0,17
N. Evora	10,10	10,13	9,19	8,25	6,50	2,68	1,94	3,14	0,13	0,15	0,19
A. Copello	9,99	10,01	9,49	8,27	6,93	2,27	2,21	2,53	0,11	0,16	0,17
L. Sands	10,25	10,14	9,50	8,52	7,26	2,48	2,10	2,36	0,11	0,15	0,17
A. Girat	9,86	9,88	9,14	8,15	7,06	2,47	2,32	2,45	0,12	0,15	0,17
Y. Li	9,89	9,99	9,18	8,15	6,94	2,64	2,26	2,57	0,11	0,14	0,14
I.Spasovkhodsky	10,06	10,09	9,35	8,24	7,11	2,39	1,97	2,67	0,12	0,17	0,18
J. Gregorio	10,42	10,36	9,42	8,28	7,11	2,48	1,75	2,62	0,11	0,15	0,19

Table 1b. Parameters of kinematics men finalist WCh, 2011. Daegu (Seo et al., 2011)

Atletičar	Results (m)	Stride length (m)					Relative distance %			Angle of take-off ~ (º)		
		2L	1 L	HOP	STEP	JUMP	HOP	STEP	JUMP	HOP	STEP	JUMP
C. Taylor	17,96	2,40	2,37	6,19	5,29	6,62	34	29	37	10	13	18
P. Idowu	17,77	2,52	2,24	6,67	5,64	5,60	37	32	31	13	14	22
W. Claye	17,50	2,42	2,31	5,77	5,43	6,47	33	31	36	11	13	21
A. Copello	17,47	2,51	2,35	6,40	5,38	5,84	36	31	33	14	15	21
N. Evora	17,35	2,39	2,25	6,44	5,18	5,84	37	30	33	13	13	20
C. Olsson	17,23	2,63	2,54	6,37	5,09	5,99	37	29	34	13	13	17
L. Sandsa	17,21	2,59	2,41	6,63	4,77	6,19	38	27	35	13	11	14
B. Compaore	17,17	2,62	2,59	6,32	5,23	5,93	36	30	34	12	14	18
Mean	17,46	2,51	2,38	6,35	5,25	6,06	36,5	29,86	34,12	12	13	**19**

Atletičar	Horizontal velocity (m/s)					Vertical velocity (m/s)			The Contact (s)		
	2 L	1 L	HOP	STEP	JUMP	HOP	STEP	JUMP	HOP	STEP	JUMP
C Taylor	10,25	10,57	9,70	8,61	7,33	1,78	1,92	2,43	0,13	0,17	0,18
P. Idowu	10,36	10,67	9,65	8,11	6,53	2,15	2,05	2,60	0,13	0,17	0,18
W. Claye	10,08	10,27	9,77	8,57	7,33	1,85	1,99	2,76	0,13	0,17	0,17
A. Copello	9,99	9,94	8,14	7,96	6,71	1,88	2,05	2,59	0,15	0,18	0,20
N. Evora	10,16	10,19	9,49	8,35	6,67	2,27	1,89	2,45	0,13	0,17	0,20
C. Olsson	9,95	10,16	9,35	8,07	7,33	2,13	1,87	2,16	0,13	0,18	0,20
L. Sandsa	10,18	10,28	9,36	8,43	7,50	2,20	1,68	1,81	0,13	0,18	0,18
B. Compaore	10,43	10,66	9,71	8,26	6,91	1,97	2,04	2,18	0,13	0,17	0,18

3. Results and discussion

Among the factors that contribute to per-formance in the triple jump are the a horizontal velocity of the body's centre of mass' (BCM) attained during the approach, the conversion of horizontal-to-vertical velocity during the sup-ports and the harmonious relationship between the flight time and the support time among the phases of the jump (Hutt, 1988; Portnoy, 1997; Yu, Hay, 1996). Performance in the triple jump is strongly correlated with the BCM velocity (both horizontal and vertical) and BCM height at the take-offs for the hop, the step and the jump (Al-Kilani, Widule, 1990; Fukashiro, Miyashita, 1983).

Since the hop and the jump exhibit a small variance in the distance of the triple jump (Hay, Miller, 1985), performance is dependent on the optimum execution of the step and particularly the transition between the hop and the step. The success of the execution of the transition from the hop to the step is defined by high velocity, wirde knee angle during the support and short contact time (Jürgens, 1998).

Table 2 shows the results of the differences between men's finalists of the World Championship in Berlin, 2009 and Daegu, 2011. By inspecting the Table 2, it can be concluded that of the total number of analyzed kinematic parameters in five parameters (23 %) statistically significant differences were recorded. Statistically significant differences were recorded at the stepping angle of rebound (Hop°), T=3,689, p<0,003 where athletes in Berlin had a higher average angle rebound (14,75°) compared to athletes in Daegu (12,43°) which is consistent with the results (Schiffer, 2011; Pavlović, 2016). Also, the vertical velocity in the rebound recorded significant differences in VVo Hop (m/s), T = 5,269; p < 0.000. Athletes in Berlin achieved a higher average vertical speed of rebound (2,48m/s) than athletes in Daegu, (2,04 m/s). Apart from the angle of the rebound and the vertical speed of the rebound, statistically significant differences between the finalists for the level of p<0,001 and p<0,005 were achieved during the contact phase of the take-off (T = -3,580; p < 0,003), the step (T = -5,193; p < 0,000), the jump (T = -1,966; p<0,071), where it is evident that athletes in Berlin had, on average, shorter time contact phase in all three parameters (hop, step, jump). It can be concluded that they also had a larger generated force at the moment of reflection, which is a product of a higher speed of movement.

In relation to Berlin, the Daegu finalists in 2011 had almost identical values. The average length of the jump was 6,35 m (36,5 %), the steps were 5,25 m (29,86 %) and the jump 6.06m (34,12 %). The horizontal acceleration of the jibe was 9,40 (m/s), step 8,30 (m/s) and jump 7,04 (m/s). Here, there is also a reduction in horizontal speed after each leap and an increase in the contact phase duration. Also, the angle of reflection is inverted and increased with a reduction in the horizontal velocity (from 12-19°), and with each jump, the vertical acceleration increased, which was also the highest in the jump (2,37 m/s). It can be concluded that the finalists in Daegu had a higher average jump length, higher horizontal velocity, duration of the contact phase and angle of reflection, which resulted in a larger overall average jump length of 17.46m and the best jump of 17,96m (C. Taylor) versus Berlin and a score of 17,73m (P. Idowu).

Also, the inverted relationship between the speed and the angle of rebounding of the competitors was observed in both finals, which is a consequence of the speed reduction in each jump, where the triple jumpers use a larger swing with free extremities. The contact phase time increases with each subsequent jump, which is also a consequence of a decrease in the speed of movement, with the contact phase lasting longer, as confirmed by athletes in Daegu. The average contact phase for men's finalists at the 2009 Berlin WC was (0,12s) in hopping, (0,15s) in stepping, in jumping (0,17s) and was shorter than the average phase of contact at the WC in Daegu (0,13-0,17-0,19s), which is in line with the research (Pavlović, 2016).

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

Men	**World Championship**	**Mean±Std.Dev.**	**T-value**	**p Sig. (2-tailed) **0,001;*0,005**
2 LS (m)	Berlin	2,58±0,19	1,068	0,305
	Daegu	2,49±0,09		
1 LS (m)	Berlin	2,41±0,13	,860	0,405
	Daegu	2,35±0,10		
Length of Hop (m)	Berlin	6,35±0,19	-,003	0,998
	Daegu	6,35±0,30		
Length of Step (m)	Berlin	5,29±0,28	,263	0,797
	Daegu	5,25±0,28		
Length of Jump (m)	Berlin	5,79±0,14	-2,104	0,055
	Daegu	6,08±0,37		
Hop %	Berlin	36,50±1,41	,597	0,561
	Daegu	36,00±1,83		
Step %	Berlin	30,38±1,41	,651	0,527
	Daegu	29,86±1,68		
Jump %	Berlin	33,13±0,83	-1,300	0,216
	Daegu	34,14±2,04		
Hop°	Berlin	14,75±1,04	3,689	0,003
	Daegu	12,43±1,40		
Step°	Berlin	14,00±1,51	1,198	0,252

	Daegu	13,14±1,21		
Jump°	Berlin	20,63±2,39	1,208	0,249
	Daegu	19,00±2,83		
HVo 2L (m/s)	Berlin	10,13±0,23	-,085	0,934
	Daegu	10,14±0,14		
HVo 1L (m/s)	Berlin	10,14±0,21	-1,315	0,211
	Daegu	10,30±0,25		
HVo Hop (m/s)	Berlin	9,37±0,20	,106	0,917
	Daegu	9,35±0,56		
HVo Step (m/s)	Berlin	8,29±0,14	-,072	0,944
	Daegu	8,30±0,26		
HVo Jump (m/s)	Berlin	6,99±0,22	-,407	0,691
	Daegu	7,06±0,40		
VVo Hop (m/s)	Berlin	2,48±0,13	5,269	0,000
	Daegu	2,04±0,19		
VVo Step (m/s)	Berlin	2,06±0,19	1,614	0,131
	Daegu	1,92±0,13		
VVo Jump (m/s)	Berlin	2,63±0,23	1,602	0,133
	Daegu	2,40±0,32		
Contact of Hop (s)	Berlin	,12±0,01	-3,580	0,003
	Daegu	,13±0,01		
Contact of Step (s)	Berlin	,15±0,01	-5,193	0,000
	Daegu	,17±0,01		
Contact of Jump (m)	Berlin	,17±0,02	-1,966	0,071
	Daegu	,19±0,01		
RESULTS (m)	*Berlin*	*17,28±0,29*	*-1,484*	*0,162*
	Daegu	*17,50±0,28*		

Legend: Mean (average value); SD (standard deviation); T-value (coefficient of t-test value); p Sig. (2-tailed)

An analysis of triple jump technique has shown that at most triple jumpers the increase in the results depends on the increase in the accumulation of the first two jumps, the level of speed-up capabilities and the increase in the speed of the running start. On the basis of the analysis of both finals, it can be concluded that the following percentages of the relationship between the individual lengths of the individual jumps and optimal angles of reflection are optimal in the triple jump of men: first jump-hop (36,25 % and 13,6°), second jump-step (30,12% and 13,8°), the third jump-jump (33,64 % and 19,81°) or the sum of the jumps: I + II = 66,37 %; II + III = 63,76 %, which is in line with the research (Panoutsakopoulos, Kollias, 2008; Stefanović, Bošnjak, 2011; Pavlović, 2016). In addition to the speed of running start and the intensity of the impulse force of the rebound, the rejection of the swing of the arms and the swinging legs on the body of the jumper is significantly influenced by the reactive power of the jumper during all three impulses of the reflecting force, as well as the relation of the individual parts of the body with respect to the pad in all transition positions of the triple jump. The ratio of "length of jumps" of the first ranked from WCh in Berlin, 2009. P.Idowu was 36-30-34%, of the second-ranked N. Evora 37-31°-32 %, and of the third-ranked A. Copello 34-33-34 % with almost identical value of step lengths and the trend of growth of the reflection angle and duration of the contact phase at all three competitors. On the Daegu WCh in 2011, the first-ranked C.Taylor had a ratio of jumping lengths of 34-29-37 %, second-ranked P. Idowu had 37-32-31 %, and third-ranked W. Claye had 33-31-36 % with the trend of the growth of the reflection angle and contact phase at the competitors, which occurs as a consequence of the falling speed of the competitors, longer contact with the surface and compensatory movements with extremities (Pavlović, 2016).

Triple jump is performed according to the rules of the IAAF so that after the running start, the jumper first pounces on the leg with which he is reflected, then leaps on his leg, which will be reflected in the final third jump. During the running start, the jumpers gradually raise the speed of the running that maximizes in the last steps of the running start, which are similar to the jump steps in the long jump. The reflective leg is placed on a reflecting board in relation to the long jump, and the angle of taking-off at the first jump is 5-7° lower than the angle of the long jump (Idrizović, 2010), which results in a smaller elevation angle.

It is known that the result in the triple jump (flight length) depends on the horizontal velocity, the intensity of the impulse of the rebound force, the angle of the rebound, the height of the TT after each rebound from the ground, and the optimal length of the first, second and third jump (Stefanović, Bošnjak, 2011; Pavlović, 2016). The world's best triple jumpers jumping over 17 m before the rebound reach the speed of over 10m/s. The elevation angle in the triple jump is smaller than at the long jump and ranges from 16°-18°, thanks, in particular, to the large horizontal (about 9 m/s) and the vertical (about 2.5 m/s) velocity at the moment of reflection (Pavlović, 2016). In order to achieve a large horizontal velocity, it is necessary for the jumper to develop the speed of the running start in the last meters over 9 m/s, which is in line with the research (Hutt, 1989; Mendoza et al., 2009). A larger angle of reflection affects the loss of horizontal velocity as well as the lifting of the jumper's center of gravity, causing greater impact forces and muscular strain during the next landing, adversely affecting the next two jumps (step, jump). According to some authors (Tončev, 2001; Pavlović, 2010; 2016), in the setting of a reflective leg, the jumper forces the pressure on the path by the inertia of the body's movement (the average impact of the vertical reaction in the first jump is 3500N, in the second 5000N and in the third 3500N).

Almost identical results have been confirmed in studies by Perettunen, Kyrolainen, Komi, Heionen (2000), which analyze the impact impulse of the lower extremities. The greatest pressure occurs on the fifth and the last part of the foot with the exceptionally large electromyographic activity of the nervous muscular system of legs and hip joints (Stefanović, Bošnjak, 2011), which confirms that the triple jump is an extremely demanding and potentially dangerous discipline. The length of the space which the jumper jumps with the first jump is the largest (more than 35 %), especially because the fact that during the rebounding on the appropriate leg, the TT projection is located just behind the surface of the support. This reduces the intensity of the rebound impulse, i.e. the intensity of the horizontal component of the reaction force of the pad. Due to such a heavy load, the reflective leg and partially the spinal column, bend, causing the stretching of the current muscles, significantly reducing the pressure of the inertial force of the body. As soon as the resistance of elongated muscles exceeds this pressure, a very strong myometric muscle contraction occurs.

The reflective leg and body of the jumper are very fast stretched out in the actual joints, directing the body to the height and forward to the stage of the step which is somewhat shorter (Berlin, Daegu about 30 %). The angle of reflection is below 16°, as has also been shown in this study, and it confirms the statements of some authors (Miller, Hay, 1986; Bowerman et al., 1999; Mihajlović, 2010; Schiffer, 2011; Pavlović, 2016). In Berlin and Daegu, the length of the first jump (hopping) was about 6,35m (36,5 %) which is almost identical with the finalists at the WC in Stuttgart (Mendoza, 2008). The hopping is performed by a reflection of a stronger leg, setting the foot closer to the projection of the center of gravity of the body, somewhat differently than in other jumping disciplines. In this way, it disables the triple jumpers to move upward, and it allows the horizontal speed of movement to be achieved and which is required for two more jumps. By a quick scratching step the leg is set firstly on heel, then with a full foot in the racing, and in the jumping variant, more by the outer vault of the feet on the board, at an angle between 60° and 70°. A slight drop and pushing forward of the pelvis is noticed, without interrupting the action from the running. The first jump (hopping) has a decisive influence on the horizontal speed, especially in the racing variant, followed by a reflection. After the reflection, there is an extension in all three joints of the reflective leg. After this stretching in the joint of the reflective leg the first phase of the flight is formed, characterized by a high-raised swing leg bent in the knee (approx. 103°) in the position of the step with the tendency of moving forward-upward and with a slight inclination of the body forward. This first step should be lower, so as not to disturb the achieved launching speed, which is decreasing (more than 9 m/s).

This is in line with the results of this study where it is evident that the horizontal jump speed (HVoHop) in Berlin was 9,37 m/s and in Daegu 9,35 m/s, with a further downward trend, which is also confirmed by the results of the Mendoza et al (2008).

After the rebound starts the so-called breakthrough pause, in which a jumper tries to hear how successful the rebound was. In the middle part of the flight phase (third of the jump) there is an active shift of the legs, where the swinging leg is lowered forward-downward-backward, with the circular movement of the lower leg, and the stepping leg is strongly bent into the knee forward-upward. This change in the leg is very energetic with the characteristic scratching lowering and elastic setting of the reflective leg on the ground. The reflective leg does not bend too much, it is placed first on the heel and later on the foot, closer to the projection of the TT jumper, so as not to have a greater effect of the reaction of the surface, which would produce a negative effect on the next step (II jump) that the jumper begins with even more energetic swinging of the knees of the swinging leg than in the first jump. The movement of the swinging (forward) leg is forward-upward, taking a position similar to the racing step. In the course of the step, the carcass of the jumper is upright in a jumping variant or in a slight inclination forward. Hands perform compensatory movements depending on the jumper's technique, with the basic aim of being in the best position for the third jump. Hands have an effect of action and reaction to the upper part of the body, when a jumper tries to pass the inertia of movement and achieves a better position for the third jump. Landing at the end of the second jump is attacking and it is important for the entire length of the triple jump, and is the consequence of a significant loss of speed obtained in the first two jumps (about 8,00 m/s), when the jumper with swinging of the hands and the explosive power of the legs strives to achieve as large a reflection angle as possible (Berlin, 20,6°; Daegu 19°), resulting in the greater length of the jump, more than 5,50m (about 34 %). A smaller horizontal velocity allows an energetic rebound using the muscular contractile component as opposed to the dominant elastic in the first two jumps (Stefanović, Bošnjak, 2011).

With a decrease in the speed of movement and an increase in the reflection angle, the contact phase is increased, which was recorded in both athletic championship finals (0,12-0,19s), also evident in the Mendoza et al. (2008); Panoutsakopoulos, Kollias, 2008. The mechanisms based on which the conversion of the horizontal velocity in vertical is performed, are extremely complex and can be defined using a coefficient (Yu, 1999), that is, the ratio of the loss of horizontal velocity in a linear relation with the increase in the vertical velocity, which is confirmed in this study. It has been proven that for the success in triple jump the most important factors are maintaining horizontal speed during the rebound, step, jump, as well as preventing the decay during the depreciation phase in the second jump, the angle of reflection, active hand or arm blockage combined with the free leg swing (Bowerman, Freeman, 1998), which again depends on the selected technique of triple jump.

An analysis of the kinematic parameters of triple jumper athletes points out that athlete finalists in Berlin had a higher average vertical speed of the rebound (2,48m/s), a shorter duration of contact phase in all three jumps and angle of reflection. However, in most of the analyzed kinematic parameters, there were no statistically significant differences between these two finals.

What was common was the fact that the athlete finalists (Berlin, Daegu) used the so-called dominant rebound technique with the dominance of the rebound (I jump-36,50 %), step (II jump-29,86-30,37 %) and jump (III jump-33-34,12 %). The same technique, so-called „rebound dominance“, was also used by the winner of the WC in Helsinki, Polish athlete, Zdislaw Hoffman (17.42 m), with proportions of 38-33-29 % and the winner of the II World Championship in Rome 1987, Bulgarian Hristo Markov (17,92m), with a jump ratio 36-30-34 %. Based on all the kinematic parameters (which did not show statistically significant differences) shown in the tables, it can be concluded that the individual does not adapt to the technique, but the technique must be adapted to his physical and technical potentials, which means that the competitor will choose the technique, not the opposite.

Also, the analyzed biomechanical parameters showed unevenness among athletes, which is the product of their training process and the technique they perform. There is no technique in the triple jump which could be recommended to every jumper, following and taking into account his individual characteristics. The final solution in the rebound dominant, jumping dominant or balanced technique must be the result of the physical and technical qualities of the athlete (Idrizović et al., 2015).

4. Conclusion

The research was carried out with the aim of determining the differences in the kinematic parameters of the triple jumper 16 male athletes, finalists at WCh in Berlin, 2009 and WCh in Daegu, 2011. The obtained results confirmed the differences in most of the measured kinematic parameters of triple jump. However, statistically significant differences were recorded only in five out of 22 (23 %) kinematic parameters. Statistically significant differences were recorded at the hopping angle (Hop°), T=3,689; p < 0,003 where male athletes in Berlin had a higher average angle of rebound (14,75°) compared to athletes in Daegu (12,43°). Also, the vertical velocity in the rebound recorded significant differences in VVo Hop (m/s), T = 5,269; p < 0,000. Athletes in Berlin achieved a higher average vertical speed of the rebound (2,48 m/s) than athletes in Daegu, (2,04 m/s). In addition to the rebound angle and the vertical speed of the rebound, statistically significant differences between the finalists for the level of p<0,001, p<0,005 were achieved during the contact phase of the rebound (T = -3,580), step (T = -5,193), jump (T = -1,966), where it was recorded that athletes in Berlin had, on average, shorter time of contact phase in all three parameters (hop, step, jump). It can be concluded that they also had a larger generated force at the moment of reflection, which is a product of a higher speed of movement. Also, the inverted relationship between the speed and the angle of rebounding of the competitors was observed in both finals, which is a consequence of the speed reduction in each jump, where the triple jumpers use a larger swing with their free extremities. In relation to Berlin, the Daeegu finalists in 2011 had almost identical values. The average length of the jump was 6,35 m (36,5%), the steps were 5,25 m (29,86 %) and the jump 6.06 m (34,12 %). The horizontal acceleration of the jibe was 9,40 (m/s), step 8,30 (m/s) and jump 7,04 (m/s). Here, there is also a reduction in horizontal speed after each leap and an increase in the contact phase duration. Also, the angle of reflection is inverted and increased with a reduction in the horizontal velocity (from 12-19°), and with each jump, the vertical acceleration increased, which was also the highest in the jump (2,37 m/s). It can be concluded that the finalists in Daegu had a higher average jump length, higher horizontal velocity, duration of the contact phase and angle of reflection, which resulted in a larger overall average jump length of 17.46 m and the best jump of 17.96 m (C. Taylor) versus Berlin and a score of 17,73 m (P. Idowu).

In general, it is evident that there are noted the differences between two finals (with or without statistical significance). However, what is confirmed is the fact that the kinematic parameters with the correct technique are the precondition for good results of the competitors as confirmed in previous research (Portnoy, 1997, Jürgens 1998; Panoutsakopoulos, Kollias, 2008; Kyröläinen et al., 2007), of course with good conative and cognitive characteristics (Pavlović et al, 2016).

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