Turk J Kin 2017; 3(4): 60-69
www.turkishkinesiology.com Original Research

# The differences of kinematic parameters high jump between male and female finalists World Championship Daegu, 2011

Ratko Pavlović

*Faculty of Physical Education and Sport, University of East Sarajevo, Bosnia and Herzegovina*

**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 high jump. The sample included 6 men and women athletes who competed in the finals of the World Championships (Daegu, 2011) and a total of 11 kinematic parameters were selected. The results were obtained by applying the T-test module for small independent samples, confirming the differences between men and women's finalists in Daegu, 2011. Statistically significant differences were recorded only in four (4) out of eleven (11) kinematic parameters (36%). Significant differences were recorded in the following parameters where the motor abilities (speed and explosive power) were manifested: maximum body center height (T=6.870; $p<0.05$), maximum horizontal velocity of the body center (T=3.134; $p<0.05$), the horizontal velocity of the center of gravity of the body (T=3.087; $p<0.05$) and the vertical velocity of the center of gravity of the body (T= 15.844; $p<0.05$).

**Key words.** Finalist athletes, high jump, kinematic parameters.

## Introduction

High jump is a very attractive athletic discipline which counts in the so called altitude or vertical jumps. In comparison to other jumps, this technique is based on a different biomechanical basis. The jumper goes over the bar, facing back, during the transverse position of the body. That position is suitable for connected transmission of body parts over the bar with the usage of compensatory effect. Transverse transit over the bar also has an impact on the increase of the speed of horizontal transit of the body over the bar and on successful lifting of the highest point of the trajectory of the body gravity center (BGC). From the mechanical point of view (maximal height of the jump) high jump is composed of three reference heights: the height of the body gravity center in the moment of leg placement on the base, the height of the body gravity center in the moment of completion of launching (a moment before leaving the base), the height of launching of the body gravity center, which is determined by the vertical speed of the jumper (Hay, 1993; Pavlović, 2016).

We can say that the launching is the most important element of the overall technique of the high jump because starting vertical speed of the launching of the body gravity center of the jumper is detected, or horizontal component is transformed into vertical. The launching is conducted with both left and right legs, depending on which side of the bar is the jump-off is done, i.e. if it is a right-handed or left-handed jumper. The launching starts with the first contact of the launching leg with the base, and it ends in the moment of toe separation from the base. This phase depends on previously done preparatory actions of the jumper and correct timing.

Corresponding Author: R. Pavlović, e-mail; pavlovicratko@yahoo.com

To cite this article: Pavlovic R. The differences of kinematic parameters high jump between male and female finalists World Championship Daegu, 2011. Turk J Kin 2017; 3(4): 60-69.

The take-off phase is defined as the period of time between the instant when the take off foot first touches the ground (touchdown) and the instant when the toe looses contact with the ground (take-off). The peak height of the jumper's centre of mass (CM) during the flight over the bar is dependent on the height and the vertical velocity of the CM at toe-off. This in turn is governed by the jumper's vertical velocity at the instant of touchdown and the vertical impulse transmitted via the takeoff foot to jumper's body during the take-off phase. The height of the jumper's CM when the toe looses contact with the ground depends on his/her physique and body position at that instant. (Dapena, 1990; Hay, 1993).

Positioning of the launching leg is done by long running step with the transition over the heel onto the full foot, in front of the vertical projection of the knee from 15º to 30º, hips around 45º and shoulders 90º. If the inclination of the jumper is towards the center of circular trajectory, the foot of the launching leg in the moment of the launching will be closer to the bar from the projection of the other body parts (knee-hip-shoulders). The distance of the launching place from the bar is bigger if the jumper comes to a place of launching in a higher running speed.

Dapena et al. (1990) found a positive relationship (r=0.79) between the horizontal velocity at the end of the approach and the vertical velocity of the CM the end of the take-off phase. Dapena and Chung (1988) suggest that a fast approach run can help the jumper to exert a larger vertical force to the ground.

The result of the competitor is the difference between the maximal height of the launching of the body gravity center and the distance between the bar and body gravity center of the jumper. The efficiency of the jump is increased in accordance with the increase of the launching speed, by optimizing of the launching angle and decreasing of the distance between the bar and BGC of the jumper in the moment of crossing over the bar (Stanković & Raković, 2010). That tells us that the success in the high jump depends on rational transmission of BGC, as well as individual segments of the body over the bar, or technique by which the jump is done. Body height is also important because the BGC of taller individuals is located on a bigger height in comparison with shorter people. Women elevate their bodies over the bar which is 25 cm maximum higher from them, while that difference in men is up to 50 cm. American Franklin Jacobs (173cm-2,32m) and Swedish Stefan Holm (181cm-2,40m) surpassed their height for 59 cm. The length of the run-up depends on the height of the jumper, level of physical competence and some distracting factors (e.g. wind). The jumper starts running from 8-11 steps, and varies between 6-17 steps, almost vertical to the bar (65º-90º), and then they run circularly by coming closer to the bar with the angle of 25º-40º, holding the inclination on inner side, as with every other running in curve. In order to overcome the effect of centrifugal force in the arched part of the track and conduct optimal jump, the inclination towards the center of the arched part of the run-up is conducted. All elements of the run-up phase have to be in the function to transfer the part of the horizontal speed into vertical speed in the most efficient way, and thus achieve a bigger vertical component of the BGC movement during the ending of the launching (Mihajlović, 2010; Pavlović, 2016).

In the last three steps the longest length is acquired and the decrease of BGC happens due to the decrease of the angle in knee joint, especially in the last step before launching, in order to increase the effectiveness of the triceps (141º-148º), ant the angle of the vertical axle on the horizontal level (the angle of launching) is around 80º-110º. The biggest horizontal speed of the run-up top jumpers achieve on 3-5 meters before launching (7,5-7,8m/s), having in mind that it is the highest is the penultimate meter (7,8-8,4m/s), while in the ultimate it decreases (6,6-7,3 m/s) and the speed of the step shortens for around 45 cm as a consequence of the hard base reaction, whose force achieves the value of 350-600kg. The best players have the average values of the third step length from the launching amount to 215-220cm, penultimate 220-230cm, ultimate 195-200 cm, and in women 175-180cm, 180-185cm, 170-175cm. As you can see, the longest one is the penultimate, and the last step is the shortest (Idrizović, 2010).

In the phase of the last resistance, the jumper starts expansion of the launching leg by contraction of actual musculature with central support. In the same time the other swinging leg of the curve in hip knuckle and brings it to the launching leg in the upwards direction in order to stop the movement abruptly by the influence of antagonist muscles. In that way kinetic energy, acquired by the swing transforms into potential (in comparison with the body) which brings to ration of the body around longitudinal axis which is the extension of conducted arched momentum. During the end of the movement amplitude, launching leg is stretched and shoulders are raised, while arms are also stretched and the jumper is in the phase of ascent. It is proved that optimal angle of the launching is 55º-63º, and that during the speed of the launching from 4.2-5.0 m/sec the height of the jump from 200-221cm can be obtained. During the phase of the flight rotations of the jumper around the sagittal axis are expressed and the jumper brings their body by punctual stretching into transitional positions which are manifested successively (Tončev, 2001). During the flight the bar is behind his back side, and in the moment when BGC is located at the top of the ballistic curve, it is in front of the bar, so the axis of shoulders and hips are parallel with the bar. The best high jumpers transfer BCG above the bar on the height of 6-9 cm and it represents the result of the effects of kinetic chains which make compensatory movement happen, or concentric and eccentric musculature contractions, especially during the crossing of the lower extremities. After the crossing of the body and thighs over the bar, concentric contraction of the triceps happens in the knuckles of the knees, and lower legs are raised. Synchronized with these movements, under the influence of myometric contraction of abdominal wall mild flexion happens in knuckles of the spine and landing on the ground happens. Morphological parameters have significant effect on result success. According to Pavlović (2012, 2013), the average height of male finalists of the Olympic Games in Beijing 2008 amounted to 190,25cm, weight was 78,87kg, BMI 21,89kg/m$^2$. However, even among the high jumpers, apart from the gender, there are shorter ones, but that does not mean that they would not have a good result. The height is only one of the necessary parameters. The technique has an impact on the result, where there are competitors who, even besides a smaller body height make good results by jumping up to 40cm more than their own height (S. Holm). Also, what is important are motor indicators, explosiveness, flexibility and the speed. The participation of these abilities in the technique of the performance defines the technique of high jumpers, if it is going to be "fast" or "strong" flopper.

The different variations of the flop techniques enable the utilisation of the best physical capacity of the each individual jumper. Therefore, it seems that there is not a single, ideal technique for achieving good results and jumpers with different body types, physical characteristics and performance techniques have good possibilities to compete successfully in the highest level (Isolehto et al., 2007).

Ritzdorf (2008), according to Idrizović, (2010), names individual kinematic parameters which are determined in the best jumps of the five first-classified on the VI World Championship in Athens in 1997. The average speed of launching amounted to 7.40m/s and launching angle was 49.2°. The speed of horizontal launching was 3.93m/s and it was 4.59m/s of the vertical launching. So called "fast" flop of J. Sotomayora sets apart, having the highest speed of the launching (8.04m/s), but what is obvious is the decrease of horizontal speed in the moment of set-off (3.58m/s). This speed is transfers into the speed of vertical launch, which is the highest (4.80m/s) in comparison with T. Forsyth, who has "strong" flop and the lowest speed of the launch (6.94m/s) but the biggest horizontal (4.08m/s) and vertical speed of the launch (4.45m/s).

The speed of horizontal amortization, vertical launch, the angle of the launch and technique are very important elements for the overall result. The average speed of horizontal amortization of finalists from Helsinki amounted to 7.78m/s, (min. 7.28m/s-max. 8.29m/s), the speed of vertical launch was 4,30m/s, (min.4,06m/s-4,61m/s), the angle of launch 51.11° with very short contact phase (175ms). The average maximal height of BCG was 2.31m and the leap was 2.26m (Idrizović, 2010).

The purposes of study (Isolehto et al., 2007) were to determine how the maximum height of the jumper's centre of mass (CM) during the flight phase of the high jump is dependent on the kinematic variables of the take-off and to update current knowledge about the development and performance of the Fosbury Flop technique. The best jumps of the finalists at the 2005 IAAF World Championships in Athletics were filmed and analysed. The authors confirmed earlier findings that the vertical velocity and height of the CM at the end of the take-off phase together determine the height of the flight. The most important factor related to vertical velocity at the moment the take-off foot loses contact with the ground is the the CM position when the foot touches down for the takeoff. CM height at this point is related more to arm technique than physique.

It is obvious that besides morphological dimensions, kinematic parameters have impact on technical performance and result success in high jump (Dapena & Chung, 1988; Dapena et al., 1990). However, it is not known if there are differences between male and female high jumpers and if they are significant in kinematic parameters. Because of that, the aim of this study is to analyze and determine eventual differences between relevant kinematic parameters of male and female high jumpers who won medals on World Championship in Daegu in 2011.

## Materials & Methods

The population defined in the research has included top athletes in the High Jump World Championship in Daegu, 2011. The sample included a total of 6 male and female finalists, who participated in the High Jump Final. The variables of kinematics parameters:

1. Foot contact time (ms)
2. Peak CM height (m)
3. Peak Horizontal CM Velocity (m/s)
4. Take off angle (°)
5. CM Velocity Horizontal at take-off (m/s)
6. CM Velocity Vertical at take-off (m/s)
7. Knee joint angle at take-off phase (last stride contact°)
8. Knee joint angle at take-off phase (last stride extension°)
9. Knee joint angle at take-off phase (take off contact°)
10. Knee joint angle at take-off phase (take off max. flexion°)
11. Knee joint angle at take-off phase (take off extension°)

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.

## Result & Discussion

According to the men's finals results, the average jump height of the top three athletes was 2.34 ± 0.02 m, and the average maximum CM height was 2.65 ± 0.01 m. The average time 49/207 of foot contact at takeoff was 0.15 ± 0.04 seconds. The average takeoff angle toward the bar was 48.7 ± 1.6°. The average horizontal CG velocity at the actual takeoff was 7.97 ± 0.41 m/s. The mean horizontal and vertical velocities of the jumpers' CM at the touchdown phase were 4.31 ± 0.21 m/s and 4.91 ± 0.05 m/s. The mean knee joint angle at the last stride was 143,1 ± 4,7° but it decreased to 140,9 ± 7,2° at touchdown; the average angle of the knee joint was 170.8 ± 8° but it increased to 172.8 ± 3.2° at touchdown. The lowest mean of the knee joint angle was 138.5 ± 14.8°.

In high jump competitions, the jumpers are categorized into Single-Arm (S) and Double-Arm (D) types according to their arm actions at touchdown. Categorizations of Bend (B) and Half-Bend (HB) are used according to how the jumpers swing their leading legs at touchdown (Ae, 1990 according to Kim, Kwon, Wi, Kim, & Lee, 2011). At the 2011 IAAF World Championships in Daegu, the arm action of J. Williams, the gold medalist, was of the Single-Arm type while the arm actions of A. Dmitrik (silver medalist) and T. Barry (bronze medalist) were of the Double-Arm type. In addition, the leading leg action of J. Williams was of the Half-Bend type, while that of the other medalists was of the Bend type. It can be concluded that the efficient kinematic matching of arm actions and the actions of leading legs at touchdown are S-HB and D-B.

There was not a big difference between the takeoff body angles of the gold medalist J.Williams (49.8°) and of the bronze medalist T. Barry (49,4°), but the takeoff body angle of A.Dmitrik (46.9°), the silver medalist, was significantly lower than the others'. In addition, among the vertical and horizontal CM velocities, the horizontal velocity of A. Dmitrik was comparably higher than the other medalists. Though the maximum CM height of A. Dmitrik, 2.64 meters, was the same as that of the gold medalist, J. Williams, this result demonstrates the added difficulty in clearing the bar due to the low takeoff angle. In the case of the bronze medalist T. Barry, he recorded the greatest maximum CM height at 2.66 meters, but his horizontal velocity (7.51 m/s) was slower than that of the gold medalist (8.32 m/s) and the silver medalist (8.07 m/s). In 2007 Osaka competition, D. Thomas won the gold medal with the result of 2.35 m. (Kim et al., 2011) and 7.87 m/s for horizontal velocity. Hence, for a better result, it is necessary to increase the horizontal velocity.

Moreover, J. Williams cleared 2.34 meters, which was the same as the results of D. Thomas and Y. Rybakov at the 2007 Osaka competition. Gold medalist J. Williams' maximum horizontal and vertical velocities at the end of the takeoff phase were 8.32 m/s and 4.97 m/s, which were greater than the velocities of D. Thomas (7.57 m/s, 4.64 m/s) and Y. Rybakov (7.57 m/s, 4.45 m/s). However, the duration of J. Williams' foot contact was 0.14 sec, which was shorter than those of D. Thomas (0.18 sec) and Y. Rybakov (0.192 sec). This means that J. Williams might have had a better result if he had taken more time at foot contact, which would have transformed the horizontal energy into vertical movement.

**Table 1.**
Parameters of kinematics male finalist WCh, 2011. Daegu (Kim et al., 2011).

| Name | Result (m) | Foot contact time (ms) | Peak CM height (m) | Peak Horizontal CM Velocity (m/s) | Take off angle (deg°) | CM Velocity at take off (m/s) | | Knee joint angle at take-off phase (deg°) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Last Stride | | Take off | | |
| | | | | | | Horizontal | Vertical | Contact | Extension | Contact | Max. flexion | Extension |
| Jesse Williams (USA) | 2.35 | 140 | 2.64 | 8.32 | 49.8 | 4.2 | 4.97 | 145.4 | 147 | 161.7 | 127.2 | 171.5 |
| Aleksey Dmitrik (RUS) | 2.35 | 110 | 2.64 | 8.01 | 46.9 | 4.56 | 4.88 | 146.2 | 142.7 | 174.1 | 155.3 | 175.4 |
| Trevor Barry (BAH) | 2.32 | 190 | 2.66 | 7.51 | 49.4 | 4.18 | 4.88 | 137.7 | 132.9 | 176.7 | 133.1 | 170.5 |
| Mean | 2.34 | 150 | 2.65 | 7.95 | 48.7 | 4.31 | 4.91 | 143.1 | 140.9 | 170.8 | 138.5 | 172.8 |

In this competition, the average backward body lean angle at the point of touchdown was 34.6 ± 2.5°, which was lower than those of the athletes at the 2007 Osaka event, 42.3 ±2.02°. It can be said that the difference between backward body lean angles was influenced by the maximum horizontal velocity and the horizontal velocity after touchdown of the medalists in the 2011 Daegu IAAF Championships. The velocities of the athletes in Daegu were higher than the velocities of the athletes at the 2007 Osaka competition. Moreover, the average physical height of the athletes at the 2007 Osaka event (1.94 ± 0.04 m) was greater than that of the medalists at the 2011 Daegu event. J. Williams and A. Dmitrik are both 1.84 m. Because of their shorter stature, they achieve a greater horizontal velocity causing a lower backward body lean angle at the point of touchdown. This allowed them to perform much better than the athletes in earlier competitions. At touchdown, J. Williams' knee joint angle was 161.7°, A. Dmitrik's was 174.1° and T. Barry's was 176.7°. After touchdown, J. Williams' knee joint angle was 171.5°, A. Dmitrik's was 176.4° and T. Barry's was 170.5°. In 2007, D. Thomas recorded touchdown and post touchdown angles of 161° and 171°, while Y. Rybakov had angles of 170° and 174°. The gold medalists, J. Williams in 2011 and D. Thomas in 2007, had the same value of knee joint angles at and after touchdown. Moreover, the difference between the knee joint angles from the moment of touchdown to when foot lost contact was about 10° for both athletes. Compared to the two gold medalists, the knee joint angles of the other athletes were very different. In particular, their knee joint angles at the point of touchdown were greater than those of the gold medalists. The two gold medalists most actively used their knee joints at the moment of touchdown. This means that their body movements were efficient enough to transform their horizontal movement into increased vertical movement after takeoff. Moreover, their active knee joint movement at the moment of touchdown led kinetic energy originated by touchdown toward potential energy. Hence, it can be concluded that their active knee joint movement contributed to their gold medal performances (Kim et al., 2011).

The average of the top three athletes' final results was 2.02 ± 0.02 m, and the mean of the maximum CM height was 2.12 ± 0.18 m. The average time of foot contact at take-off was 0.16±0.01 sec. The average take-off angle toward the bar was 48.6 ± 3.2°. At the point of take-off, the average horizontal velocity of the jumpers' CM was 6.99 ± 0.33 m/s. The mean horizontal and vertical velocities of the jumpers' CM at the point of touchdown phase were 3.66 ± 0.45 m/s and 4,13 ± 0,07 m/s. The average backward body lean angle at touchdown was 30.5 ± 4.6°, the average inward body lean was 34.3 ± 5.6°, and the average angle of the trunk of the body was 36.9 ± 5.3°. The mean of the knee joint angle at the last stride was 142.9 ± 6.2°, but it increased to 150.4 ± 9°at touchdown. At touchdown, the angle of the knee joint was 171 ± 7°, but it decreased 168.7 ± 3.3° upon touchdown. The lowest mean of the knee joint angle was 144.5 ± 10.2°.

The gold medalist, A. Chicherova, recorded a longer foot contact time (0.16 sec.) than B. Vlasic, the silver medalist, and A. Di Martino, the bronze medalist. Also, the maximum height (2.22 m) of A. Chicherova s CM and her maximum horizontal velocity (7.37 m/s) when crossing the bar were higher than the other competitors'. The bronze medalist, A. Di Martino, cleared 2 m even though she is shorter (1.69 m) than the others. It is notable that she brought her CM to a maximum height of 1.97 m when she cleared 2 m. The medalists' body angles toward the bar after take-off were 46.6° (A. Chicherova), 46.9° (B. Vlasic), and 52.2° (A. Di Martino). They all recorded take-off angles greater than 45°. It appears that A. Di Martino◎s take-off angle was higher than the others'. After take-off, the mean body angle of the women high jump medalists was similar to that of the men medalists, 48.7°. But at the take-off phase, the body angles of the women gold and silver medalists were 3° smaller than the men medalists'. In addition, when their touchdown foot lost contact with the ground, the medalists' mean horizontal velocity was over 3 m/s, and their vertical velocity was over 4 m/s. In particular, A. Chicherova's vertical velocity was 4.18 m/s greater than those of B. Vlasic and A. Di Martino. Also, the gold medalist's, A. Chicherova's, maximum horizontal velocity was 7.37 m/s, which was greater than other two medalists' horizontal velocities. This meant that A. Chicherova's body movements were efficient enough to transform her horizontal movement at touchdown into a better vertical movement than those of B. Vlasic and A. Di Martino (Kim et al., 2011).

**Table 2**.
Parameters of kinematics female finalist WCh, 2011. Daegu (Kim et al., 2011).

| Name | Result (m) | Foot contact time (ms) | Peak CM height (m) | Peak Horizontal CM Velocity (m/s) | Take off angle (deg) | CM Velocity at take off (m/s) | | Knee joint angle at take-off phase (deg°) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Last Stride | | Take off | | |
| | | | | | | Horizontal | Vertical | Contact | Extension | Contact | Max. flexion | Extension |
| Anna Chicherova (RUS) | 2.03 | 160 | 2.22 | 7.37 | 46.6 | 3.59 | 4.18 | 138.2 | 153.3 | 163.0 | 133.4 | 172.3 |
| Blanka Vlašić (CRO) | 2.03 | 150 | 2.17 | 6.87 | 46.9 | 3.89 | 4.15 | 140.7 | 157.5 | 174.1 | 146.8 | 165.8 |
| Antonietta Di Martino (ITA) | 2.00 | 140 | 1.97 | 6.74 | 52.2 | 3.14 | 4.05 | 149.9 | 140.3 | 175.9 | 153.3 | 168.0 |
| Mean | 2.02 | 150 | 2.12 | 6.99 | 48.6 | 3.66 | 4.13 | 142.9 | 150.4 | 171.0 | 144.5 | 168.7 |

**Table 3.**
Differences of kinematic parameters finalists of high jump (t-test independent sample test).

| Variables | Gender | Mean ± SD | t | p |
|---|---|---|---|---|
| Foot contact time (ms) | Men | 0.158 ± 0.04 | -0.139 | 0.896 |
| | Women | 0.150 ± 0.01 | | |
| Peak CM height (m) Max.Hight TT (m) | Men | 2.65 ± 0.01 | 6.870 | 0.002* |
| | Women | 2.12 ± 0.13 | | |
| Peak Horizontal CM Velocity (m/s) Max. | Men | 7.95 ± 0.41 | 3.134 | 0.035* |
| | Women | 6.99 ± 0.33 | | |
| Take off angle (° ) | Men | 48.70 ± 1.57 | 0.066 | 0.951 |
| | Women | 48.57 ± 3.15 | | |
| CM Velocity Horizontal at take - off (m/s) | Men | 4.31 ± 0.21 | 3.087 | 0.037* |
| | Women | 3.54 ± 0.38 | | |
| CM Velocity Vertical at take- off (m/s) | Men | 4.91 ± 0.05 | 15.844 | 0.000* |
| | Women | 4.13 ± 0.07 | | |
| Knee joint angle at take-off phase (last stride contact°) | Men | 143.10 ± 4.69 | 0.037 | 0.972 |
| | Women | 142.93 ± 6.16 | | |
| Knee joint angle at take - off phase (last stride extension°) | Men | 140.87 ± 7.23 | -1.428 | 0.227 |
| | Women | 150.37 ± 8.97 | | |
| Knee joint angle at take - off phase (take off contact°) | Men | 170.83 ± 8.02 | -0.028 | 0.979 |
| | Women | 171.00 ± 6.98 | | |
| Knee joint angle at take - off phase (take off max. flexion°) | Men | 138.53 ± 14.82 | -0.575 | 0.596 |
| | Women | 144.50 ± 10.15 | | |
| Knee joint angle at take - off phase (take off extension°) | Men | 172.47 ± 2.59 | 1.553 | 0.195 |
| | Women | 168.70 ± 3.31 | | |

* $p < 0.05$

In the women s competition, the mean backward body lean angle at touchdown was 30.5 ± 4.6° which is smaller than that of the male competitors, which was 34.6 ± 2.5°. In particular, B. Vlasic, the former champion, had a similar take-off angle to A. Chicherova, but Vlasic's maximum horizontal velocity, maximum CM height, and vertical velocity after take-off were lower than those of A. Chicherova. It can be said that her backward body lean angle (25.2°) was not enough to efficiently transform horizontal movement to vertical movement. Also notable in A. Chicherova's performance was that her knee joint angle at the point of touchdown and after touchdown was almost same as J. Williams', the men's high jump champion in Daegu, and D. Thomas', the men's champion at the 2007 Osaka competition. Moreover, the difference between the maximum and minimum flexion in the knee of Chicherova's take-off leg was about 9°. Female competitors' knee flexion was as great as the male gold medalists. Lastly, the knee joint angles of B. Vlasic and A. Di Martino at take-off were greater than the actual toe take-off point. In comparison, A. Chicherova's knee joint angle at the actual toe take-off was greater than it was for J. Williams and D. Thomas. Hence, this difference in knee joint angle at take-off helped A. Chicherova to receive her gold medal at the IAAF World Championships, Daegu 2011 (Kim et al., 2011).

In tables 1 and 2 the kinematic parameters of male and female winners of WC in Daegu (Korea) in 2011 are presented. The thing that is identical in male and female jumpers is the time of the contact of the feet (150ms), almost identical angle of the launch, contact of the last step and angle of the contact during the launching. In other parameters they are different, as expected. Male participants had bigger average horizontal and vertical speed, individual angles in the phase of launching and contact. What can be observed is the maximal height of BGC and the results are lower for about 30 cm from the maximal height of BGC. That is the indicator that they had a good technique and that the height of the participant is not crucial factor in acquiring the results. Actually, it used all biomechanical parameters, especially the transfer of BGC above the given height of the bar (the moment of hyperextension of the body).

In order to obtain results that made them the winners of medals, men had average maximal horizontal speed of the BGC 7.97m/s. Horizontal speed of the launching of the BGC was 4.31 m/s, and vertical was 4.91m/s. In comparison to men, women had average maximal horizontal speed of the BGC of 6,99m/s, which is almost for 1 sec lower than in men. Horizontal speed of the launching of the BGC of the female finalists was 3.66 m/s, and vertical was 4,13m/s. It can be concluded that both men and women medal winners had higher vertical speed of the launching from horizontal speed, for about 0.5 sec. It can be observed that the first-positioned Jesse Williams and Ana Chicerova had bigger horizontal speed of BGC (Williams, 8.32m/s; Chicerova 7.37m/s) and bigger vertical speed of launching of the BGC (Williams, 4.97m/s; Chicerova 4.18m/s) from second-positioned and third-positioned, which means that the speed of the launching of the BGC is extremely significant. Also, men had bigger average values in values of the angles of the knee joint in the phase of the contact, maximal flexion and extension. That is the indicator that they made stronger myometric-plyometric contraction of caudal extremities, based on better strength from female finalists. They enabled for themselves better flexion of the knee joint based on usage of the force m. quadriceps to the point in which quadriceps can withstand the bending, in order for the explosive moment of stronger stretching of m. quadriceps of the launching leg (Stefanović, 1992; Pavlović, 2016).

It can be concluded that male and female high jumpers differ in values of most of the kinematic parameters. However, the question is if those differences statistically significant. In order to check this assumption, and in order to determine statistically significant differences in kinematic parameters, we used the module of the T-test for small independent samples (Table 3). From the total of 11 kinematic parameters which are analyzed, only in four parameters (36%) the differences that were recorded were significant on the level of $p<0.001$ and 0.005 in favor of male jumpers. In the remaining seven parameters (64%) that was not the case- The differences were recorded in maximal height of the BGC ($T=6.870$; $p<0.002$), where male jumpers elevated their BGC on 2,65m in comparison to 2.12m, which was expected if morphological and motor parameters are taken into account. The differences were recorded in maximal horizontal speed of the BGC ($T=3.134$; $p<0.035$), where horizontal speed of the BGC in male participants was 7.95m/s, and in female jumpers it was 6.99m/s. Significant differences were recorded in parameters of horizontal and vertical speed of the launching of the BGC during the launching, where statistically significant difference was recorded ($T=3.087$; $p<0.037$). Male jumpers made horizontal speed of the launching of the body (4.31m/s) in comparison to women (3.54m/s). Also, the biggest difference was recorded in parameter of vertical speed of the launching of the BGC ($T=15.844$; $p<0.000$). Male finalists made faster vertical movement of the launching of the BGC (4.91m/s) in comparison to the speed made by female finalists (4.13m/s). In the remaining kinematic parameters the differences are there, but they were not statistically significant.

If we compare the results of our research with the results of Ritzdorf (2008) we can observe the differences in kinematic parameters of male jumpers. The differences are obvious in the launching angle, where in finalists of WC in Athens in 1997 the angle of launching was bigger (49.2°) in comparison to WC in Daegu (48,7°). However, finalists in Daegu had bigger speed of horizontal launching (4.31m/s) in comparison to 3,93m/s in Athens and the speed of the vertical launching (4.91m/s) in comparison to 4.59m/s on WCh in Athens. The speed of horizontal amortization, vertical launching, angle of the launching and technique are very important elements for the overall result (Idrizović, 2010). The average speed of horizontal amortization of the finalists from Helsinki was 7,78m/s, (min. 7.28m/s-max. 8.29m/s), the speed of vertical launching was 4.30m/s, (min.4.06m/s-4.61m/s), the angle of the launching was 51.11° with very short contact phase (175ms). Average maximal height of the BGC obtained was 2,31m and the height that was jumped over was 2.26m.

Body height is also important for the reason that BGC in tall people is on a higher position than in shorter people. Women elevate their bodies over the bar which is maximally for 25 cm higher from them, while that difference in men is up to 50 cm. Research data proves that body height is an important factor in high jump (Pavlović, 2012; 2013) where the average height on OG in Beijing in 2008 was 190.25cm, and for women it was 183.37cm. Besides body height an important parameter is also horizontal speed which is obtained by the jumper in the last steps of the run-up and that ranges from 7.5-8.4m/s, and in the last step it decreases to 6.6-7m/s as a consequence of the reaction of the hard ground whose force comes up to a value of

350-600kg (Jović, 2006; Pavlović, 2016). It is also confirmed in our research that the speed of the BGC for both genders. The average movement speed of BGC in men jumpers was 7.95m/s in the range of 7.51m/s (Barry) up to 8.32m/s (Williams). The average speed of BGC of female jumpers was 6.99m/s in the range of 6.74m/s (Di Martino) up to 7.37m/s (Chicherova).

As a consequence of a bigger speed of run-up, horizontal (4.31m/s) vertical (4.91m/s) speed of launching of BGC in male jumpers increases. In a somewhat smaller scale that manifested in female jumpers too, in both parameters (horizontal and vertical speed of launching). The results of this research made it possible, from one side, to determine statistically significant differences in kinematic parameters, depending on the gender of the jumper, which was confirmed by the research. On the other hand, linear dependence on kinematic parameters of the speed of horizontal and vertical component of the launching of the BGC was determined as relevant parameters with obtained results. Overall, parameters which manifest motor skills of the jumpers (speed, explosive power) detect statistically significant differences between genders. In comparison to them, parameters which are less defined by motor skills of the jumpers, and more based on the technique of the movement (flexion angles, extension, ground contact duration) do not detect significant differences and as such they do not represent relevant parameters for the result success of the high jump of the finalists of WC in Daegu, in 2011.

## Conclusion

The research was carried out with the aim of determining the differences in the kinematic parameters of the High jumper athletes, finalists at World Championship in Daegu, 2011. The sample included a total of 6 men and women competitors. The obtained results confirmed the differences in most of the measured kinematic parameters of high jump. However, statistically significant differences were recorded only in four out of eleven (36%) kinematic parameters of level significance ($p< 0.001$ i 0.005) in favor of male athletes. In the remaining seven parameters (64%) this was not the case.

Differences are recorded in maximal height of the BGC ($t=6.870$; $p<0.002$), which is expected if morphological and motor parameters are taken into account. The differences recorded in maximal horizontal speed of BGC ($t=3.134$; $p<0.05$), where horizontal speed of BGC in male participants was 7.95m/s, and in female it was 6.99m/s. Significant difference were recorded in parameters of horizontal and vertical speed of the launching of BGC during the jump-off where statistically significant difference was recorded ($t=3.087$; $p<0.05$). Male jumpers made bigger horizontal speed of the launching of the BGC (4.31m/s) in comparison to females (3.54m/s). Also, the biggest significant difference was recorded in parameter of vertical speed of the launching of BGC ($t=15.844$; $p<0.05$). Male finalists made faster vertical trajectory of the launching of BGC (4,91m/s) in comparison to the speed which was made by female finalists (4.13m/s).

It is evident that kinematic parameters are relevant for completion of result success in high jump in both genders. The observed and statistically significant differences relate to parameters for the assessment of motor skills, mainly to speed and explosive power. Exactly these skills contributed to the result success in differences between genders.

## References

Dapena J. Mechanics of rotation in the Fosbury-flop. Med. Sci. Sports Exerc, 1990; 12: 45-53.

Dapena J. The high jump. In V. Zatsiorsky (Ed.), Biomechanics in Sport (pp. 284-311). Blackwell Science: Oxford, 2000.

Dapena J, Chung CS. Vertical and radial motions of the body during the takeoff phase of high jumping. Med. Sci. Sports Exerc, 1988; 20: 290-302.

Dapena J, Mc Donald C, Cappert J. A Regression Analysis of high jumping technique. J Sport Biomechanics, 1990; 6: 246-261.

Hay JG. The Biomechanics of Sports Techniques (First/Fourth Edition). Prentice-Hall, Inc, Englewood Cliffs, 1993.

Idrizović K. Atletika I i II. [Athletics I, II. In Serbian] Univerzitet Crne Gore: Biblioteka biomedicinskih nauka, 2010.

Isolehto J, Virmavirta M, Kyröläinen H, Komi P. Biomechanical analysis of the high jump at the 2005 IAAF World Championships in Athletics. IAAF, 2007; 22(2): 17-27.

Jovović V. Atletika biomehanika-tehnika i metodika. [Athletics biomechanics-technique and methodology. In Serbian] Nikšić. Filozofski fakultet-studijski program fizičke culture, 2006.

Kim SS, Kwon MS, Wi UR, Kim KM, Lee JM. Men's High Jump-Biomechanics Research Report from the IAAF World Championships, Daegu 2011. Scientific Research Project Biomechanical Analyses at the 13 IAAF World Championship, Daeegu, 2011 Final Report High Jump.

Kim KM, Lee JM, Kim SS, Kwon MS, Wi UR. Women's High Jump-Biomechanics Research Report from the IAAF World Championships, Daegu 2011. Scientific Research Project Biomechanical Analyses at the 13 IAAF World Championship, Daegu, 2011 Final Report High Jump.

Mihajlović I. Atletika. [Athletics.InSerbian] Novi Sad: Fakultet sporta i fizičkog vaspitanja, 2010.

Pavlović R. The morphological status of the finalist in jumping disciplines at the Beijing Olympics. Sport Science-International Scientific Journal on Kinesiology, 2012; 5(2): 43-48.

Pavlović R. The morphological status of the female finalist in jumping disciplines at the Beijing Olympics. Sport Mont, 2013; 11(37-39): 116-125.

Pavlović R. Atletika 2. [Athletics 2. In Serbian] Niš: Udruženje književnika, Branko Miljković'', 2016.

Stefanović Đ. Atletika 2-tehnika. [Athletics 2-technics. In Serbian] SIA. Beograd, 1992.

Stanković D, Raković A. Atletika. [Athletics-In Serbian] Niš: Fakultet sporta i fizičkog vaspitanja, 2010.

Tončev I. Atletika tehnika i obučavanje. [Athletics-Techniques and Training. In Serbian] Novi Sad: Fakultet fizičke culture, 2001.