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BIOKINEMATIC CHARACTERISTICS OF THE TRIPLE JUMP TECHNIQUE IN QUALIFIED ATHLETES

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Abstract

The purpose of the study is to investigate the biokinematic characteristics of the triple jump technique in qualified athletes.

Material and methods. The technique of the final attempts of qualified triple jumpers during the 2023 World Athletics Championships was analyzed. The following methods were used in the work: analysis and synthesis of scientific and methodological literature, analysis of video materials, methods of mathematical statistics. The video of the final attempts was used, provided for public use by the International Athletics Federation (World Athletics). The attempts were recorded by four video cameras installed on the side of the treadmill at a distance of 2,5 m, the height of the video camera mounted on a tripod was 1,5 m. Two of the four video cameras recorded video at a frequency of 25 frames per second, the other two video cameras recorded video at a frequency of 1300 frames per second. Video analysis of the final attempts and processing of biokinematic parameters of the technique were determined using the Dartfish and Kinovea programs. All statistical data were processed in the statistical analysis program IBM SPSS Statistics version 28.0.1.0.

Results. The metric, time, angular, and speed characteristics of the take-off technique are determined; push-off; jump; step; jump for highly skilled triple jumpers. Based on the analysis of the triple jump technique indicators, the optimal biokinematic parameters of the technique that athletes need to have in order to achieve high competitive results were obtained.

Conclusions. To achieve high competitive results in the triple jump, the following technical parameters must be used. The take-off speed should reach 10.40 m s^{-1} or more, the length of the last take-off step should be 2,20-2,40 m; the pace of the last step is 4-5 steps/s. The push-off; from the bar should last 0.100-0.133 s; the push-off; angle reaches 65-70°; the speed of departure of the general center of mass of the body is 9.60 m s^{-1} and more. The jump should last no more than 0,660 s. During the jump, the high height of the overall center of body mass should be 1.30-1.45 m; upon landing, the speed of the general center of mass of the body is 9,20 m s^{-1} or more.

The second push-off should last 0,160-0,180 s, the push-off angle is 60-65°. The take-off speed of the general center of body mass in a step should be 8,80 m s^{-1} or more. The optimal step duration is 0.450-0.520 s, step length is 5.20-5.50 m, the maximum height of the overall center of body mass is 1.24-1.30 m; upon landing, the speed of the general center of mass of the body is 8.50 m s^{-1} or more.

The third push-off should last 130-166 s. The push-off angle is 63-70°. The take-off speed of the general center of mass of the body in a jump is from 8 m s^{-1} and more. The optimal duration of the jump is 0.750-0.780 s; maximum height of the overall center of body mass 1,10-1,22 m; upon landing, the speed of the general center of mass of the body is 7 m s^{-1} or more.

When taking off and landing, the angle in the supporting leg throughout all three jumps should be 163-170°.

Key words: technique, biomechanical indicators, kinematic indicators, model parameters, highly qualified triple jumpers.

Анотація

Мета дослідження - дослідити біокінематичні характеристики техніки потрійного стрибка у кваліфікованих спортсменів.

Матеріал і методи. Аналізувалась техніка фінальних спроб кваліфікованих стрибунів потрійного стрибка упродовж Чемпіонату світу з легкої атлетики 2023 р. У роботі були використані наступні методи: аналіз та узагальнення науково-методичної літератури, аналіз матеріалів відеозйомки, методи математичної статистики. Використовувалось відео фінальних спроб, надане в загальне користування Міжнародною федерацією легкої атлетики (World Athletics). Запис спроб здійснювався чотирма відеокамерами, встановленими збоку бігової доріжки на відстані 2,5 м, висота монтування відеокамери на триногу 1,5 м. Дві з чотирьох відеокамер здійснювали запис відео з частотою 25 кадрів в секунду, дві інші відеокамери здійснювали відеозапис з частотою 1300 кадрів в секунду. Відеоаналіз фінальних спроб та обробка біокінематичних параметрів техніки визначались за допомогою програм Dartfish, Kinovea. Усі статистичні дані оброблювалися у програмі статистичного аналізу IBM SPSS Statistics версія 28.0.1.0.

Результати. Визначено метричні, часові, кутові, швидкісні показники техніки розбігу; відштовхування; скоку; кроку; стрибку у висококваліфікованих стрибунів потрійним. На підстав аналізу показників техніки потрійного стрибка отримано оптимальні біокінематичні параметри техніки які необхідно мати спортсменам з метою досягнення високих змагальних результатів.

Висновки. З метою досягнення високих змагальних результатів у потрійному стрибку повинні використовуватись наступні параметри техніки. Швидкість розбігу повинна досягати 10,40-м·$с^{-1}$ і більше, довжина останнього кроку розбігу 2,20-

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2,40 м; темп останнього кроку 4-5 крок/с. Відштовхування від планки повинно тривати 0,100-0,133 с; кут відштовхування досягати 65-70°; швидкість вильоту загального центру маси тіла 9,60 м·с$^{-1}$ і більше. Скок повинен тривати не більше 0,660 с. Упродовж скоку найвища висота загального центру маси тіла повинна бути 1,30-1,45 м; під час приземлення швидкість загального центру маси тіла 9,20 м·с$^{-1}$ і більше.

Друге відштовхування повинно тривати 0,160-0,180 с, кут відштовхування 60-65°. Швидкість вильоту загального центру маси тіла у кроці повинна бути 8,80 м·с$^{-1}$ і більше. Оптимальна тривалість кроку 0,450-0,520 с, довжина кроку 5,20-5,50 м, найбільша висота загального центру маси тіла 1,24-1,30 м; під час приземлення швидкість загального центру маси тіла 8,50 м·с$^{-1}$ і більше.

Третє відштовхування повинно тривати 130-166 с. Кут відштовхування 63-70°. Швидкість вильоту загального центру маси тіла у стрибку від 8 м·с$^{-1}$ і більше. Оптимальна тривалість стрибка 0,750-0,780 с; найбільша висота загального центру маси тіла 1,10-1,22 м; під час приземлення швидкість загального центру маси тіла 7 м·с$^{-1}$ і більше.

Під час відштовхування та приземлення кут в опорній нозі, упродовж всіх трьох стрибків, повинен становити 163-170°.

Ключові слова: техніка, біомеханічні показники, кінематичні показники, модельні параметри, висококваліфіковані стрибуни потрійним.

Introduction

The triple jump is the most coordinated and technically complex event among horizontal athletics jumps, therefore special attention is given to technical training [8, 12].

Only in the interconnected execution of a run-up, followed by a jump, step, jump and effective landing is it possible to achieve high results in competitive struggle [23].

Research on the technical parameters that are observed in athletes while performing a triple jump takes a key position in the training of athletes.

When improving the movements of a jumper, M. J. Hoffmann, J. Liu [13] noted the need to pay special attention to the angular parameters of the technique, especially to the position of the body during the run-up phase. It is the angle of inclination of the body that is one of the most important factors influencing the amplitude of movements of the arms and legs and, as a result, the length and frequency of steps changes [13].

The strict regulation of competition rules does not allow athletes to change their jump and step techniques. At the same time, the last jump is allowed to be performed using the legs bent, arched jump or hitch-kick method [7].

Despite the variety of techniques for performing a jump, G. S. Waad, A. M Sarmad [24], analyzing the structure of movements in the flight phase, recommend using the “hitch-kick” jump method, since, unlike other methods, it allows less loss of horizontal speed acquired during the third push-off [24] .

One of the priority areas of research for the triple jump technique is the study of speed parameters. Determining the optimal takeoff speed will allow you to most effectively perform take-off and flight along the optimal trajectory. [4, 6, 20].

Improving the training process of athletes over recent years, in particular the development of training methods, has contributed to an increase in their level of physical fitness, which has entailed changes in the structure of the athletes’ movements when implementing the triple jump technique.

Considering that technique is the most important component in achieving high competitive results, studying the kinematic characteristics of the movements of qualified athletes is extremely important for the effective preparation of triple jumpers.

Purpose of the study: to investigate the biokinematic characteristics of the triple jump technique in qualified athletes.

Material and research methods

The technique of 8 triple jump finalists during the 2023 World Athletics Championships was analyzed. According to the rules and regulations of the competition, all participants consented to the processing and further use of video materials. The study complied with the requirements of the Helsinki Declaration of Ethics. The following methods were used in the work: analysis and synthesis of scientific and methodological literature, analysis of video materials, methods of mathematical statistics.

A video of the final attempts was used, provided for public use by the International Athletics Federation (World Athletics). The recording of attempts was carried out by four video cameras installed on the side of the treadmill at a distance of 2,5 m, the height of mounting the video camera on a tripod was 1.5 m. Two of the four video cameras recorded video with a frequency of 25 frames per second, the other two video cameras recorded video with a frequency of 1300 frames per second. Video analysis of the final attempts and processing of biokinematic parameters of the technique were determined using the Dartfish and Kinovea programs. All statistical data were processed in the statistical analysis program IBM SPSS Statistics version 28.0.1.0.

Results

When assessing the take-off technique, the last two steps were analyzed, taking into account their key importance for further push-off. The following technical parameters were assessed: the length of the last step, the angle of placing the foot at the take-off site, the take-off speed, the ratio of the support and flight time of the last three steps of the run-up, the take-off speed, the angle of the torso. The specified characteristics of the technique of the studied athletes are presented in Table 1.

For all the studied athletes, the length of the last step was not less than 2,25 m. The coefficient of variation V = 3,17% indicates the homogeneity of the results among the studied athletes and indicates the absence of significant differences between the step length indicators.

The speed at the end of the take-off run for qualified athletes reaches an average of 10,73 m s^{-1}. The coefficient of variation V = 3,90% indicates close homogeneity of the speed indicators of the tested athletes and gives grounds to assert that there are no significant differences in the take-off speed among the triple jumpers under study.

The duration of the flight of the last step reached 0.180 s V = 25,5%, the push-off at the last step of the take-off run was within 0,066 – 0,133 s. V=12,7%. The difference in the timing parameters of the technique is primarily associated with the individual length of steps and the angle of take-off from the track during the run-up.

For all athletes, the last step tempo did not exceed 6

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Vollum 28 No. 1, 2024

Table 1

Features of the run-up technique of qualified triple jumpers (n=8)

Indicator	$\bar{X}$	σ	V (%)
Length of the last step (m)	2,28	0,07	3,17
Speed at the end of the take-off run (m s^{-1})	10,73	0,42	3,90
Duration of flight of the last step (s)	0,144	0,04	25,46
Duration of push-off in the last step (s)	0,11	0,01	12,66
Last step tempo (step/s)	4,2	0,70	16,88
Length of penultimate step (m)	2,44	0,07	2,93
Duration of flight of the penultimate step (s)	0,178	0,01	7,98
Duration of push-off in the penultimate step (s)	0,13	0,02	19,12
Penultimate step tempo (step/s)	3,3	0,4	12,4
Torso tilt at the end of the take-off run (º)	3,6	0,7	18,5

steps s^{-1} and was within 4-6 steps per second.

A study of the length of the penultimate step revealed a step length of 2.50-2.53 m in four athletes. In other jumpers studied, the penultimate step was 2,35-2,43 m. In general, the length of the penultimate step was observed at 2,44 m V=2,9%.

The time of the flight phase in the penultimate step for most qualified jumpers was 0.170-0.180 s (V= 7,98 %).

Inhomogeneous results were observed in the push-off time indicator in the penultimate step V = 19,12%. The coefficient of variation indicates significant differences in the results of a given technique parameter. For the athletes under study, take-off in the last step took 0,100-0,166 s.

The pace of the penultimate run-up step did not exceed 4,2 steps/s. The coefficient of variation for this indicator V= 12,4% indicates minor differences in the tempo of the penultimate step of the run-up among qualified triple jumpers.

Significant differences were observed in the torso tilt at the end of the take-off run V=18,5%. Some athletes have an almost straightened position of the torso, and a number of jumpers have a slight deviation of the torso back before placing their feet on the take-off bar.

It should be noted that, despite the differences in the results of this indicator, for all qualified athletes the angle of inclination of the torso at the end of the run does not exceed 7º.

To evaluate the push-off technique, the following technique parameters were determined: the angle between the thighs at the beginning of the push-off phase, the time of push-off from the bar, the angle of placing the leg at the push-off site, the push-off angle, the angle of the torso, the angle between the hips during push-off.

The studied characteristics of the take-off technique of qualified jumpers are presented in Table 2.

For all triple jumpers, regardless of the characteristics of the run-up technique, the angle of placing the foot on the bar did not exceed 74-V = 6,2%.

An assessment of the take-off technique showed the individuality of the take-off duration from the bar V = 17,75% among qualified triple jumpers. In general, despite the variety of push-off times, the duration of lift-off from the bar did not exceed 0.166 s.

Table 2

Indicators of take-off technique of qualified triple jumpers (n=8)

Indicator	$\bar{X}$	σ	V (%)
Angle of placing the foot on the bar (º)	66,5	4,1	6,2
Push-off duration (s)	0,130	0,02	17,75
The angle between the thighs at the moment of placing the foot at the take-off point (º)	34,9	9,8	27,9
Push-off angle (º)	66,2	4,0	6,0
Angle between the thighs at the moment of push-off (º)	108,3	10,3	9,5
Angle at the knee joint of the swing leg (º)	86,6	16,6	19,2
Angle at the knee joint of the push leg (º)	166,1	6,6	4,0
Initial take-off speed of the general center of mass of the body (m s^{-1})	9,81	0,58	6,0

At the beginning of the push-off phase, athletes exhibit significant differences in the amount of hip extension of 20-50˚. V=27.9. At the end of the push-off, more uniform values of the angle between the hips V=9,5% were recorded. For all qualified triple jumpers, before lifting the leg off the bar, the angle between the hips was fixed within 90-120˚.

In the push-off angle indicator, the coefficient of variation was V=6.0%. The close homogeneity of push-off angle indicators among athletes gives grounds to assert that qualified athletes typically take-off at an angle of 65-70°.

By the end of the push-off, athletes have fairly uniform indicators of the flexion angle in the knee joint of the pushing leg V = 4,0%. For most athletes, at the end of the push-off phase, the pushing leg is almost straightened at the knee joint 160-179°.

The angle in the knee joint of the fly leg at the end of take-off among qualified jumpers reached 115° V=19,2 %.

Despite the individuality of the push-off technique, all athletes showed no significant differences in the speed of take-off of the general center of body mass V = 9,85%. The coefficient of variation indicated a close homogeneity of results and gave grounds to assert that, despite the individual organized actions of athletes in the take-off process, qualified triple jumpers have almost the same efficiency in performing the take-off phase.

For all athletes, regardless of the method of performing the run-up and take-off, the take-off speed of the general center of body mass did not exceed 10 m s^{-1}.

Biokinematic characteristics of the jump are given in Table 3.

After the first push-off, the overall center of mass of the body described a parabolic trajectory. The height of the overall center of body mass reached an average of 1.40 m. The uniformity of the results V = 7,55% showed that, despite the peculiarities of the organization of actions in the flight phase of the first jump, they did not have a significant impact on changes in the

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trajectory of the athletes' overall center of body mass.

During the flight, the athletes performed a running step in preparation for the second take-off. The greatest hip extension of all jumpers was observed in the second part of the flight phase of the jump.

Table 3

Biokinematic characteristics of the triple jump of qualified athletes (n=8)

Indicator	$\bar{X}$	σ	V (%)
Angle of placing the foot on the support (º)	66,0	4,0	6,1
Jump length (m)	6,00	0,33	8,7
Jump duration (s)	0,595	0,037	6,2
Velocity of the general center of mass of the body at the end of the jump (m s-1)	9,60	0,88	10,2
The highest altitude of the trajectory of the general center of mass of the body during the flight phase (m)	1,40	0,10	7,6
Largest angle between thighs during flight (º)	106,6	16,7	15,6
Angle at the knee joint of the pushing leg at the end of the jump (º)	163,9	3,4	2,0
Angle at the knee joint of the swing leg at the end of the jump (º)	111,9	27,2	24,3
Angle between thighs at end of jump (º)	52,7	18,7	35,5

Athletes who were more able to maintain the initial velocity of the overall center of body mass had a wider hip extension of up to 122°. In others, the hip extension was smaller and reached 100°. This discrepancy also affected the homogeneity of the results in this indicator. The coefficient of variation was at the level of average homogeneity V=15,6%.

Analyzing the jump technique, it was found that, regardless of the specifics of the run-up and take-off technique, all the leading triple jumpers studied had fairly uniform indicators of the length of the first jump V of 8,73%. The length of the jump averaged 6,02 m and did not exceed 6.35 m.

The jump ended with an active raking placement of the foot on the support at an angle of 60-70º. The coefficient of variation V= 6,1% indicated that there were no significant differences in the technique of placing the leg on the support at the end of the jump.

In general, no significant differences were found in the timing of the jump V=6,24%. The first of three jumps lasted on average 0,595±0,037 s.

At the end of the first of three jumps, the velocity of the general center of mass of the body was in the range of 8-10.50 m s^{-1}. Minor discrepancies V = 10,2% between the speed indicators of the general center of body mass are associated primarily with the individuality of the run-up technique and push-off from the bar.

The average jump length was 6,00±0,23 m.

All jumpers are characterized by an almost straightened position of the pushing leg on the support after the first of the jumps V = 2,0%. The angle in the knee joint of the pushing leg varied in the range of 160-170º.

Despite the similarity in the technique of placing the leg on the support after the first jump, quite significant differences were observed among the athletes in the angle of flexion of the swing leg at the beginning of the landing V = 24.3%. A number of athletes straightened their fly leg up to 120-130º at the moment of landing, while for others the angle in the knee joint of the fly leg did not exceed 100º.

Differences in the amount of hip extension during the flight phase of the jump also influenced the angle between the hips at the end of the jump V = 35,5%. Despite the average angle of 52,7±18,7º for individual jumpers, the angle between the thighs reached almost 80º.

From the moment the pushing legs were placed on the support, preparation for the step began.

Biokinematic indicators of technique during the second take-off of qualified triple jumpers are shown in Table 4.

Indicators of uniformity of parameters of the second push-off technique were in the range of 1,7-11,8%. The resulting coefficients of variation indicated that there were no significant differences in second take-off technique between skilled triple jumpers.

Table 4

Technique indicators of qualified triple jumpers during the second push-off (n=8)

Indicator	$\bar{X}$	σ	V (%)
Push-off duration (s)	0,167	0,02	11,77
Push-off angle (º)	63,6	3,6	5,6
Angle at the knee joint of the swing leg (º)	118,7	7,7	6,5
Angle at the knee joint of the push leg (º)	165,3	2,9	1,8
Angle between thighs (º)	84,6	6,2	7,3
Departure speed of the general center of mass of the body (m s^{-1})	8,90	0,88	9,80

The second push-off lasted no more than 188 s and averaged 0,167 ± 0,02 s.

The push-off angle, as when taking off from the bar, did not exceed 70° on average.

At the moment the leg lifted from the support, the angle between the hips was in the range of 78-92º.

The supporting leg of all triple jumpers was almost straightened at the knee joint 160-170º. The swing leg was bent at the knee joint at an angle of 110-126º.

The speed of departure of the general center of mass of the body decreased compared to the first push-off and amounted to 8,90±0,88 m-s^{-1}.

During the step, the athlete jumps from the push leg to the fly leg. Features of the step technique of qualified triple jumpers are given in Table 5.

For all qualified triple jumpers, the angle of placing the fly leg on the support at the end of the step did not exceed 70 °. Comparison of the average angular parameters of the jump and step revealed the absence of significant differences in the features of the technique of placing the leg on the support.

During the step, athletes experienced more significant losses in the horizontal speed of the overall center of body mass. At the end of the step, the speed of the general center of body mass averaged 8,66 ± 0,75 m s^{-1}.

The loss of horizontal speed also affected the decrease in step length for all qualified jumpers and did not exceed 5,70 m, V = 4,3%.

In contrast to the jump, during the step there were significant differences in the organization of the athletes' actions in

the flight phase. A number of athletes, having taken off from the support, began to prepare for landing in a step, and the rest in the second part of the step. The height of the overall center of body mass for all athletes had fairly uniform indicators V = 4.5% and averaged 1,31 ± 0,06 m. The angle between the hips at the end of the step averaged 51 ± 9,3˚, V = 18,2%.

Table 5

Biokinematic characteristics of the step of qualified triple jumpers (n=8)

Indicator	$\bar{X}$	σ	V (%)
Angle of placing the swing leg on the support (º)	65,3	3,1	4,8
Step length (m)	5,30	0,23	4,3
Step duration (s)	0,475	0,044	9,3
Velocity of the general center of mass of the body at the end of the jump (m s-1)	8,66	0,75	8,7
The highest altitude of the trajectory of the general center of mass of the body during the flight phase (m)	1,31	0,06	4,5
Largest angle between thighs during flight (º)	114,7	8,7	7,5
Angle at the knee joint of the swing leg at the moment it is placed on the support (º)	163,2	4,3	2,6
Angle of the knee joint of the pushing leg at the end of the step (º)	113,8	9,9	8,7
Angle between hips at end of step(º)	51,0	9,3	18,2

During the flight phase of the step, the angle between the hips was quite uniform V = 7,5% in some athletes reached 127˚and on average was 114,7 ± 8,7˚,

The duration of the step did not exceed 0,550 s.

During landing in a step, the swing leg stood on the support almost straightened at the knee joint 163.2±4.3˚. The pushing leg was bent at the knee joint at an angle of 113,8±9,9˚.

The average step length was 5,30±0,23 m.

At the moment of placing the swing leg on the support, the athlete proceeded to perform a jump.

Biokinematic indicators of the third push-off technique of qualified triple jumpers are given in Table 6

Table 6

Technique indicators of qualified jumpers during the third push-off (n=8)

Indicator	$\bar{X}$	σ	V (%)
Push-off duration (s)	0,155	0,02	14,2
Push Angle (º)	63,5	3,7	5,8
Angle at the knee joint of the swing leg at the end of the push-off (º)	164,2	4,2	2,6
Angle of the knee joint of the pushing leg at the end of the push-off (º)	107,0	10,9	10,2
Angle between thighs at end of push-off (º)	95,3	13,7	14,3
Departure speed of the general center of mass of the body (m s-1)	8,08	0,62	7,7

The duration of the third push-off from the support did not exceed 0.183 s. Among the athletes studied, an average homogeneity of results was recorded V = 14,2%.

The push-off angular indicators for all athletes were uniform V=5.8% and did not exceed 70˚.

At the end of the push-off, the swing leg comes off the support almost straightened; the angle at the knee joint averaged 164,2±4,2˚. The angle in the knee joint of the pushing leg at this moment varied in the range of 96,4-100˚.

The angle between the thighs at the end of the third push-off averaged 95,3±13,7˚, V=14,3%.

At the end of the third repulsion, the athletes showed uniform speed parameters of the general center of body mass, V = 7,7%. The speed of departure of the general center of mass of the body did not exceed 8,20 $m \cdot s^{-1}$.

Having pushed off the support with their swing leg, the athletes performed the jump mainly by bending their legs.

Jump technique indicators are given in Table 7.

Table 7

Jump technique indicators of qualified triple jumpers (n=8)

Indicator	$\bar{X}$	σ	V (%)
Highest height of the overall center of body mass (m)	1,12	0,12	10,8
Jump length (m)	5,90	0,24	3,8
Jump duration (s)	0,769	0,026	3,3
Velocity of the general center of mass of the body at the end of the jump ($m\ s^{-1}$)	7,38	0,65	8,8

Analyzing the jump technique, minor differences were identified in the highest height of the trajectory of the general center of body mass V = 10.8%, which is associated with the individual style of performing the jump. Depending on the method of jump, the height of the overall center of body mass ranged from 1.09-1.26 m.

Regardless of the method of performing the jump, all athletes had approximately the same jump length V=3.8%. The jump length averaged 5.90±0.24 m.

The time parameters of the jump technique were fairly uniform, 3.3%. The jump for all qualified jumpers lasted from 0.717 to 0.800 s.

At the end of the jump, the speed of the general center of body mass averaged 7.38 ± 0.65 m s-1.

The triple jump was completed at the moment of landing in the jump.

Discussion

Studying the take-off technique, Y. S. Bae, Y. J. Park [5], L. A. Bridgett [9], M. Hubert [15] determine in detail the initial speed and take-off angle. However, due to the need to effectively transfer horizontal speed to vertical speed, performing a powerful take-off, in the last steps of the run, jumpers begin to place their foot when landing closer to the projection of the general center of body mass, performing a raking foot placement on the bar [11]. We analyzed in detail the features of the technique of the last steps of the run-up and push-off in order to optimize the run-up in the triple jump.

The results of the study showed a decrease in the length of the last step of about 7.0%, which is 16-25 cm compared to the penultimate step. This affected the tempo of the last step, which increased by 27.3%.

Of the time parameters of the run-up, the most significant differences were observed in the duration of the flight phase of the last step, 0.100-0.180 s, which is associated with the athletes' attempt to adjust the length of the last step in order to accurately hit the bar.

A comparison of the time of take-off from the bar with the parameters of the run-up technique showed that for jumpers who had faster execution of the last three steps of the run-up, the take-off duration was in the range of 0.100-0.133 s. For jumpers who performed the second part of the run more slowly, the take-off duration was 0,146-0,166 s.

Analyzing the angular parameters of the push-off technique, it was found that the angle between the hips at the beginning of the push-off phase depends on the characteristics of placing the pushing leg on the bar. In athletes who performed a position of the pushing leg closer to the projection of the general center of body mass, the angle between the hips did not exceed 30 °. In other athletes, in proportion to the increase in the distance from the projection of the general center of body mass to the place where the pushing leg was placed, the angle between the hips increased.

At the end of the push-off from the bar, in athletes performing a more energetic movement of the hip of the swing leg forward, the angle in the knee joint of the swing leg was mostly 70-85 °. Less energetic movement of the hip of the swing leg forward leads to an increase in the angle in the knee joint of the swing leg to 100-115 °.

In the studies of Z. Mohammed [19], R. Pavlovic [21], it is noted that the greatest efforts should be implemented when pushing off from the bar to further maintain horizontal speed, however, optimization of the preparation of triple jumpers made it possible to improve the quality of landing [17], which allows redistributing efforts in the process of all three push-off. The study of the speed parameters of all three jumps made it possible to expand the information of S. J. Allena [2], H. Liu [18] S. R. Shabu [22] about the dynamics of speed in the triple jump. The study found that during a jump the initial speed of the general center of body mass is lost on average by 2.1%, during the second push-off the loss of speed of the general center of body mass is 7.3%, during the step the loss of speed of the general center of body mass reaches 2.7%. during the third push-off 6,7%. The data obtained showed that the greatest efforts should occur during the first and third push-off. Due to the technical complexity of the jump, athletes are unable to realize their greatest efforts in the second take-off, so the main task is to reduce the depreciation phase during the second landing in order to maintain the initial speed.

From the point of view of biomechanics, during the flight phase of the jump, the athlete's actions cannot in any way affect the speed indicators of movement of the general center of body mass [10, 16]. However, the quality of preparation for landing affects the amount of depreciation in the knee joint [14] and the quality of further push-off during a triple jump [1, 3]. For this purpose, we determined the indicators of the height of the trajectory of the general center of body mass.

The results of biokinematic analysis showed that the duration of the jump, step, jump will depend on the trajectory of the general center of body mass and its height, which will directly affect the preservation of the initial speed gained by athletes during the run-up and the quality of the push-off.

Comparative characteristics of the techniques of qualified triple jumpers made it possible to determine the optimal height of the overall center of body mass. When jumping, the height of the overall center of body mass should be 1,30-1,45 m; in steps of 1,24-1,30 m; during the jump 1,10-1,22 m.

When performing jumps with these parameters of the height of the general center of body mass, the least temporary losses and the most effective landing and push-off in a step and jump will be observed.

Conclusions.

To achieve highly competitive results in the triple jump, the following technical parameters must be used. The take-off speed should reach 10.40 m s-1 or more, the length of the last take-off step should be 2,20-2,40 m; the pace of the last step is 4-5 steps/s. The push-off from the bar should last 0.100-0.133 s; the push-off angle reaches 65-70 °; the speed of departure of the general center of mass of the body is 9.60 m s^{-1} and more. The jump should last no more than 0,660 s. During the jump, the high height of the overall center of body mass should be 1,30-1.45 m; upon landing, the speed of the general center of mass of the body is 9,20 m s^{-1} or more.

The second push-off should last 0,160-0,180 s, the push-off angle is 60-65°. The speed of departure of the general center of mass of the body in a step should be 8,80 m s^{-1} or more. The optimal step duration is 0.450-0.520 s, step length is 5,20-5,50 m, the maximum height of the overall center of body mass is 1,24-1,30 m; upon landing, the speed of the general center of mass of the body is 8,50 m s^{-1} or more.

The third push-off should last 130-166 s. Push-off angle 63-70°. The speed of departure of the general center of mass of the body in a jump is from 8 m s^{-1} and more. The optimal duration of the jump is 0.750-0.780 s; maximum height of the overall center of body mass 1,10-1,22 m; upon landing, the speed of the general center of mass of the body is 7 m s^{-1} or more.

When taking off and landing, the angle in the supporting leg throughout all three jumps should be 163-170 °.

Conflict of interest

The authors declare that there is no conflict of interest.

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