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Original Article

Individual peculiarities of long jump technique of skilled athletes

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Abstract
Introduction. The objective of the article is to identify the individual biomechanical characteristics of the long jump technique of skilled athletes. **Material and methods**. In furtherance of this objective of the study, the following methods were used: analysis of scientific and methodical literature and Internet; video shooting; biomechanical computer-based video analysis; methods of mathematical statistics. Two athletes, representatives of Ukraine and China, participated in the studies. The technology for biomechanical computer-based video analysis included two main stages: shooting with a video camera and processing the resulting videograms by means of “Dartfish”, “Motion Analysis Tools” and “BioVideo” specialized software. **Results.** A comparative analysis of the individual long jump technique of two athletes allowed to reveal statistical differences in eight biomechanical indices, which was confirmed by the Mann-Whitney test at a level of $p < 0.05$. **Conclusions**. For further technical improvement, athletes need to focus on those individual characteristics of technical skills that are the cornerstone of their success and ultimately provide the achievement of high sports results.
Key words:individualization, long jump, technical skills, technique, athlete.

Introduction.

An important component of the preparation process is the formation and improvement of the technical skills of athletes [Bobrovnik V.I., Kozlova E.K. (2008)]. The problem of studying the long jump technique and its improvement on the basis of objective quantitative biomechanical characteristics has attracted the attention of numerous experts [Brüggemann G.-P, KoszewskiD, Müller H. (1999), Scientific Research Project of the Games of the XXIV Olympiad Seoul 1988 (1990)]. In particular, the German researchers Mendoza, Nicoford [Mendoza L., Nicoford E. (2011).] studied the long jump technique of the world best track and field athletes. They estimated the kinematic characteristics of run-up, take-off and landing using a 2 D analysis with a shooting speed of 150 frames / s [Mendoza L., Nicoford E. (2011).]. Schiffer [Shiffer Y. (2011).] placed the emphasis on the most important characteristics of horizontal jumps, affecting the achievement of high sports results: high speed of running and the ability to accelerate; special speed-strength qualities; ability to take-off in the most efficient mode [Shiffer Y. (2011).].Yang Jing Tian [Yang Jing Tian(2002).] considered long jump technique improvement on the basis of double take-off. Based on identification of informative biomechanical characteristics of the long jump technique (men and women), Ukrainian experts developed models of motor actions providing the achievement of desired sports results in this type of competitions [Bobrovnik V.I., KozlovaE.K. (2008)]. Despite availability of various studies dealing with the analysis of the long jump technique, this problem remains relevant from the standpoint of studying the individual peculiarities of technical skill manifestation in the competitive activity of athletes. This is due to the fact that quite frequently technical preparation of gifted athletes with distinct individual characteristics is carried out according to generally accepted programs. This approach prevents manifestation of individuality in the competitive activity, which is the cornerstone of success in achieving high sports results.The above necessitates studying individual technique of athletes’ motor actions primarily in order to offer individual programs to reveal their talents.

Objective. To reveal individual biomechanical characteristics of the long jump technique of skilled athletes and to show possible approaches to improve their technical skills on this basis.

Material and Methods.

The following methods were used to achieve the objective of study:

- analysis of scientific and methodical literature and Internet;
- video shooting;
- biomechanical computer-based video analysis;

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- methods of mathematical statistics (descriptive statistics, correlation analysis, Mann-Whitney nonparametric test for determining statistical differences between two independent samples).

Technology of carrying out biomechanical computer-based video analysis included two main stages: shooting with a video camera and processing the resulting videograms by means of “Dartfish” (Switzerland), “Motion Analysis Tools” and “BioVideo” specialized software. The shooting was made by two GoPro HERO4 Silver video cameras mounted on tripods and located at a height of 1.3 m above the ground and at a distance of at least 20 m to a moving athlete, which corresponds to metrological requirements for spatial orientation of the cameras relative to the object of study. The shooting angle did not exceed 18° (φ<9°) [Laputin A.M. (2001)]. Video shooting of the long jump technique was carried out at the Kiev Championship (Ukraine, Kiev) and the National Youth Track and Field Championship (China, Shanghai). GoPro HERO4 Silver cameras with built-in touch displays allowed to obtain professional-quality video and provided video recording with a high resolution of 1280x720 pixels and a frame frequency of 120 frames per second.

Biomechanical analysis was carried out on a single-plane shooting. The error in determining motion temporal characteristics did not exceed the duration of the inter-frame time interval, i.e. when shooting at 120 frames / s (PAL format), this error was 1/120 s = 8 ms.

Two athletes participated in the study in order to reveal individual biomechanical indices of technique – Rezanov Aleksandr (Ukraine): date of birth – 23.12.1997; body mass – 80 kg; body length – 1,90 m; Li Wen (China) – date of birth – 02.10.1999; body mass – 78 kg; body length – 1,88 m. Studies were conducted in accordance with the Helsinki Declaration. The individual characteristics of the long jump technique of two athletes were analyzed according to the results of three successful attempts (official result of competition). Their results did not have statistically significant differences – Rezanov Alexander – 6,88 m 7,19 m, 7,29 m and Li Wen –- 6,97 m, 7,19 m, 7,35 m, respectively (p> 0.05).

The video information obtained as a result of the video shooting was processed by means of the Motion Analysis tools (version 27.3), Dartfish and Bio-Video programs developed by I. V. Khmelnitskaya at the Department Biomechanics and Sports Metrology of the National University of Physical Education and Sport of Ukraine [KhmelnytskaI.V. (2000)., KhmelnytskaI.V. (2004)]. When developing the specialized BioVideo software, the Microsoft Visual Basic 6 integrated development environment with a graphical interface was used. As a programming language, the version of Visual Basic 6.0 was used representing a multi-purpose code of symbolic instructions in the design environment. The initial data for the BioVideo program are frame files of single-plane video recording of human motor action in the .BMP, .DIB, .WMF, .EMF, .GIF, .JPG, .JPEG formats [KhmelnytskaI.V. (2000)., KhmelnytskaI.V. (2004)].

As a model of the locomotorium, a 14-segment branched biomechanical chain was used, the coordinates of which according to geometric characteristics corresponded to those of the human body bio-links position in space, whereas the reference points represented the coordinates of the main joint centers [Laputin A.M. (2001)]: suprasternal notch; right shoulder joint; left shoulder joint; right elbow joint; left elbow joint; right wrist joint; left wrist joint; right hip joint; left hip joint; right knee joint; left knee joint; right ankle joint; left ankle joint; body GCM. The localization of the centers of mass (CM) of the bio-links and the body general center of mass (GCM) was determined by means of the Bio-video program [KhmelnytskaI.V. (2000)., KhmelnytskaI.V. (2004)].

Biomechanical analysis resulted in determining the following kinematic characteristics of athlete motor actions:

- joint angles as well as angles between segments and axes - the angle of departure;
- derived parameters (linear velocities) by measuring the covered distance and the known time interval.

Energy characteristics were calculated using the formulas:

Athlete's potential energy:

$$E_{pot} = mgh$$

where: *m* – mass of athlete, kg; *g* – free-fall acceleration 9,82 m/s^2; *h* – height of body GCM above support, m

Athlete’s kinetic energy:

$$E_{кин} = \frac{m \cdot V^2}{2}$$

where: m – mass of athlete; *V*– linear velocity of athlete body GCM, m·s^{-1};

Full mechanical energy of athlete:

$$E_{full} = E_{pot} + E_{kin}$$

where E_{kin}– kinetic energy of athlete body, J; E_{pot}– potential energy of athlete body, J

Power in the take-off phase was determined as the change of the athlete’s full mechanical energy per time of take-off:

$$P = \frac{\Delta E_{полн}}{\Delta t}$$

where $\Delta E_{full} = E_{fulldep} - E_{fullplac}$; $E_{fulldep}$ – full energy of athlete body at the moment of departure, J; $E_{fullplac}$ – full energy of athlete body at the moment of support leg placement on the support, Δt — time of take-off calculated using the formula

$$\Delta t = \frac{N_{dep} - N_{plac}}{V_{shooting}}$$

where N_{dep} – frame number of videogram illustrating the end of take-off phase and the beginning of departure phase; N_{plac}– frame number of videogram illustrating the end of run-up phase and the beginning of take-off phase $V_{shooting}$– shooting speed equal to 120 fr/s.

Correlation analysis allowed to determine association of the recorded kinematic and energy indices with the result in the long jump based on 60 videograms of 15 athletes, each of which performed from 3 to 6 attempts.

Analysis of the correlation fields showed a monotonic relationship between biomechanical characteristics of the long jump technique and the result of athletes; therefore Spearman's correlation coefficient was used. As a result, informative indices were identified that have a correlation with sports result at the level of $p < 0.05$.

Comparative analysis of the long jump technique of two athletes was carried out according to the following biomechanical indices: minimum angle in the knee joint of the support leg in the take-off,°; extension angle of the hip joint of the support leg at the time of breaking off the support,°; duration of the take-off phase, s; run-up speed before take-off (last stride), $m \cdot s^{-1}$; angle of departure of the body GCM,°; speed of departure of the body GCM at the moment of leg breaking off the support, $m \cdot s^{-1}$; height of the body GCM at the moment of foot placement on the support to take-off, m; height of the body GCM in the phase of absorption during take-off, m; height of the body GCM at the moment of leg breaking off the support during take-off, m; height of the body GCM at the highest point of flight, m; length of the last run-up stride before take-off, m; length of the last but one run-up stride before take-off, m; length of the third run-up stride before take-off, m; potential energy at the moment of foot placement on the support to take-off, J; potential energy at the moment of breaking off the support, J; kinetic energy at the moment of foot placement on the support to take-off, J; kinetic energy at the moment of breaking off the support, J; full energy at the moment of foot placement on the support to take-off, J; full energy at the moment of breaking off the support, J; take-off power, W. Mathematical processing of findings was made by means of generally accepted methods described in the literature [AntomonovM.Y. (2018)] using the Microsoft Excel XP and Statistica 10.0 (StatSoft, USA) application software packages. Statistically significant differences between Rezanov Aleksandr (Ukraine) and Li Wen (China) were confirmed using the Mann-Whitney test at $p < 0.05$.

Results.

It has been established in the course of study that athletes slightly differed in anthropometric indices (body length and mass). Their average sports results (three attempts) did not have statistically significant differences $\bar{x}$ = 7,12, S = 0,21 m and $\bar{x}$ = 7,17, S = 0,19 m, respectively ($p < 0.05$). It is known that the higher the sports result, the higher the values of biomechanical indices according to which the comparative characterization of the long jump technique of two athletes is carried out, except for the duration of interaction with the support. The shorter the duration of this interaction, the higher the sports result [Bobrovnik V.I., KozlovaE.K. (2008)]. Technique comparative analysis of two athletes showed that the run-up speed at the last stride before take-off was higher in the Ukrainian athlete Me (25%, 75%) = 11,70 (11,57; 11,91) $m \cdot s^{-1}$than in the Chinese jumper Me (25%, 75%) = Me (25%, 75 %) = 10,99 (10,95; 11,18) $m \cdot s^{-1}$at statistically significant differences ($p < 0.05$) (Table 1). One should note high values of this index in both athletes. The loss of the departure speed of Aleksandr Rezanov in the best attempt (7,29 m) constituted 0,96 $m \cdot s^{-1}$, whereas that of Li Wen (7,35 m) 0,46 $m \cdot s^{-1}$at ($p < 0.05$). Lower values of the angle of departure of Me (25%, 75%) = 20,40 (20,35; 21,25)° were found in the Ukrainian athlete in comparison with the Chinese jumper Me (25%, 75%) = 22,57 (22, 49; 22,59)° ($p < 0.05$). The latter tended to take-off faster Me (25%, 75%) = 0,13 (0,13; 0,13) s than the former Me (25%, 75%) = 0,14 (0,14; 0,15) s, which gave advantage to achieve high sports results ($p < 0,05$) (see Table1). Thus, individual compensation in achieving sports results in long jumps is mainly realized at the expense of different biomechanical indices: higher parameters of run-up and departure speed and higher values of departure angle and lower indices of the duration of interaction with the support during take-off in Aleksandr Rezanov and Li Wen, respectively.Statistically significant differences in the individual technique of long jumps were observed in such indices as the height of the body GCM at the moment of foot placement on a support to take-off (see Table 1). The values of this index Me (25%, 75 %) = 1,19 (1,18; 1,20) were higher in Aleksandr Rezanov as compared to Li Wen Me (25%, 75 %) = 1,10 (1,09; 1,11) ($p < 0,05$)., The difference in this index (height of the body GCM during absorption phase in take-off) reached significant values ($p < 0.05$) (see Table 1). At the same time, statistically significant differences were not observed among the athletes at the moment of foot breaking off the support, ($p > 0.05$). In terms of potential energy values at the moment of foot placement on the support, the differences between the athletes constituted Me (25%, 75%) = 932,96 (925,12; 940,80) J and Me (25%, 75%) = 840,84 (833,20; 844,66) J, respectively ($p < 0.05$) (see Table 1). Statistically significant differences were revealed between the technique of athletes and the values of the kinetic energy at the moment of support foot breaking off the supportMe (25%, 75%) = 5152,9 (4957,01; 5230,66) J and Me (25%, 75%) = 4557,39 (4404,07; 4651,08) J, respectively ($p < 0.05$) (see Table 1).

Table 1

Individual anthropometric characteristics of skilled athletes and biomechanical indices of the long jump echnique

Biomechanical index	p	Athlete									
		Rezanov Aleksandr (Ukraine)					Li Wen (China)				
		$\bar{x}$	S	Me	25%	75%	$\bar{x}$	S	Me	25%	75%
Minimum knee joint angle of support foot during take-off phase,°	>0,05	144,54	4,13	142,18	142,16	145,75	143,82	4,89	145,89	142,07	146,61
Extension angle of support leg hip joint at the moment of breaking off the support,°.	<0,05	169,81	3,90	167,69	167,56	171,00	162,74	0,94	162,78	162,29	163,22
Take-off phase duration, s	<0,05	0,14	0,01	0,14	0,14	0,15	0,13	0,00	0,13	0,13	0,13
Run-up speed before take-off,$m \cdot s^{-1}$	<0,05	11,75	0,34	11,70	11,57	11,91	11,09	0,25	10,99	10,95	11,18
Departure angle of body GCM,°	<0,05	20,93	1,01	20,40	20,35	21,25	22,52	0,11	22,57	22,49	22,59
Speed of body GCM departure at the moment of support foot breaking off the support, $m \cdot s^{-1}$	>0,05	11,26	0,31	11,35	11,13	11,44	10,76	0,30	10,81	10.63	10,92
Height of body GCM at the moment of foot placement on the support to take-off, m	<0,05	1,19	0,02	1,19	1,18	1,20	1,10	0,02	1,10	1,09	1,11
Height of body GCM at absorption phase during take-off, m	<0,05	1,28	0,06	1,25	1,25	1,30	1,12	0,03	1,11	1,11	1,14
Height of body GCM at the moment of foot breaking off the support to take-off, m	>0,05	1,41	0,06	1,42	1,38	1,44	1,38	0,06	1,4	1,36	1,41
Length of the last run-up stride before take-off, m	>0,05	2,68	0,18	2,74	2,61	2,79	2,46	0,15	2,50	2,40	2,55
Length of the last but one run-up stride before take-off, m	>0,05	2,45	0,13	2,45	2,39	2,52	2,19	0,33	2,07	2,01	2,32
Length of third run-up stride before take-off, m	>0,05	1,76	0,05	1,77	1,74	1,79	1,74	0,05	1,73	1,72	1,76
Potential energy at the moment of support foot placement on the support to take-off, J	<0,05	932,96	15,68	932,96	925,12	940,80	838,29	11,68	840,84	833,20	844,66
Potential energy at the moment of support foot breaking of the support, J	>0,05	1102,83	47,90	1113,28	1081,92	1128,96	1052,32	44,79	1070,16	1035,76	1077,80
Kinetic energy at the moment of support foot placement on the support to take-off, J	>0,05	4106,32	199.49	4177,94	4029,42	4219,02	3650,60	853,69	3661,95	3226,62	4080,25
Kinetic energy at the moment of support foot breaking off the support, J	<0,05	5074,15	282,02	5152,9	4957,01	5230,66	4517,64	249,40	4557,39	4404,07	4651,08
Full energy at the moment of support foot placement on the support to take-off, J	>0,05	5039,27	211,42	5126,58	4962,38	5159,82	4721,85	543,60	4510,43	4413,08	4924,91
Full energy at the moment of support foot breaking off the support, J	>0,05	6176,97	239,86	6266,18	6038,93	6359,62	5569,96	239,57	5558,75	5447,48	5686,84
Take-off power, W	>0,05	7915,90	830,82	7665,17	7452,24	8254,19	6523,93	2955,63	6352,05	5005,02	7956,90
Sports result, m	>0,05	7,12	0,21	7,19	7,04	7,24	7,17	0,19	7,19	7,08	7,27

The same was true for the values of full energy at the moment of foot placement on the support. The values of this index were higher in Aleksandr Rezanov at ($p < 0.05$) (see Table 1). Statistically significant differences were also noted in the values of the extension angle of the support leg hip joint at the moment of breaking off the support ($p < 0.05$). According to this index, the Chinese athlete had the advantage (see Table 1). In addition, differences between athletes were revealed in the power of take-off ($p < 0.05$).

For other biomechanical indices, there were no statistically significant differences in the technique of long jump between athletes: the minimum knee joint angle of the support leg during take-off; speed of the body GCM departure at the moment of support leg breaking off the support; height of the body GCM at the moment of breaking off the support during take-off, length of the last three run-up strides before take-off; potential energy at the moment of the support leg breaking off the support; kinetic energy at the moment of support leg placement on the support during take-off; full energy at the moment of take-off leg placement and breaking off the support, power of take-off (see Table 1).

Discussion

Revealed fundamental differences should be used in the process of athletes' technical preparation. At the same time, a legitimate question arises as to whether disproportion should be eliminated and insufficiently developed parameters of athletes' technical skills should be improved, or it would be better to rely on their advantages. The coach often tries to increase those capacities of athlete that are largely limited genetically or are constrained by exceptionally high level of development of other qualities [Platonov V.N. (2015)]. In this case, a sports training not only fails to produce results, but often suppresses the fitness strongest points, smooths out those individual traits that would be the cornerstone of success in realizing the technical skills of a particular athlete [Platonov V.N. (2015)].

Similar conclusion was reached by specialists, who compared the indices of the developed multifunctional models with individual biomechanical characteristics of the long jump technique of the outstanding Ukrainian female jumper (world record holder in the triple jump) InessaKravets [Bobrovnik V.I., KozlovaE.K. (2017)] and considered the competitive activity modelling as the basis for individualizing the design of long-term preparation in track and field all-around. There is reason to believe that it is necessary to focus on those individual characteristics of technical skills of long jumpers, which ultimately provide the achievement of high sports results.

Conclusions.

Comparison of individual indices of the long jump technique of two athletes revealed statistically significant differences in the following biomechanical indices: extension angle of the hip joint at the moment of foot breaking off the support; take-off duration; run-up speed before take-off; angle of departure of the body GCM; height of the body GCM at the moment of foot placement on the support to take-off; height of the body GCM at the phase of absorption during take-off; potential energy at the moment of support foot placement on the support to take-off; kinetic energy at the moment of support foot breaking off the support.

For further technical improvement, athletes should focus on those individual characteristics of technical skills that are the keystone to their success and ultimately ensure the achievement of high sports results.

The directions for future research should be associated with the design of biomechanical models orienting athletes at the achievement of planned sports results with account for the individual characteristics of technical skill realization.

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