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Original Article

Individual characteristics of the long jump takeoff technique among highly skilled athletes

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Abstract:
At the current stage of athletic development, technical training within a long-term development program must be based on clearly defined reference parameters for technical movements and the athletes' level of physical fitness. Determining the biomechanical characteristics and criteria of technical proficiency in elite athletes makes it possible to optimize the training process, taking into account the individual characteristics of their long jump technique and their competitive results. This approach ensures the development of effective models for the individual technical training of elite athletes. ***Objective:*** The aim is to improve the technical proficiency of elite track and field athletes by establishing clear requirements for the individualisation of technical training for highly skilled long jumpers, taking into account the specific features of take-off technique and identifying the key components of technical readiness. ***Material and methods:*** To achieve our objectives and address the tasks set, we employed the following methods: theoretical: analysis of specialist scientific and methodological literature and online databases; instrumental: for quantitative and qualitative biomechanical analysis of the running long jump technique, a measurement study was conducted experiment was conducted using video recording followed by analysis of movements on a video computer analyser. Qualified athletes (n=32) took part in the experiment; methods of statistical data processing: descriptive statistics, parametric criteria, correlation analysis. ***Results.*** As a result of the correlation analysis, it was found that in order to achieve high sports results in the long jump from a running start, out of 58 biomechanical characteristics of the technique, it is necessary to take into account the following most important indicators: speed of departure of the general center of mass of the body (GCMB), $m \cdot s^{-1}$; horizontal and vertical components of the speed of run-up, $m \cdot s^{-1}$; angle of departure of GCMB, degree; minimum angle of bending of the knee joint of the supporting leg in the push-off phase, degree; angle of push-off, degree; length of the last three steps of the run-up, m; position of the GCMB of the athletes during push-off, m; duration of the push-off phase, s. ***Conclusions.*** The improvement of sports and technical skills of athletes is accompanied by changes in the individual characteristics of push-off movement patterns, which represents its most essential feature. As athletes' qualification improves, significant changes occur in the key indicators of push-off technique that have the greatest influence on sporting results.
Keywords: long jumpers, biomechanical characteristics, long jump technique, push-off technique, qualified athletes.

Introduction

Now that the trend towards increasing training volumes and improving athletes' physical abilities has virtually reached its limits, specialists in the field of physical education and sport are faced with the challenge of finding new ways to enhance athletes' sporting performance (Akhmetov et al., 2016; Bauersfeld & Schroter, 2015; Schnabel et al., 1994; Volker, 2003). Many of them believe that the solution to this problem lies not in the unlimited increase in the functional capabilities of athletes' bodies, but in improving the quality of their execution of motor tasks, which would be achieved primarily not through enormous energy expenditure, but through the high quality of the technique of each movement and each motor action (Bompa & Haff, 2009; Verkhoshasnky, 2012). That is precisely why technical training is widely regarded as one of the key strategic areas of modern sports training (Anderson et al., 2009; Sosanski & Zaporozanow, 1993).

In modern sport, the importance of technical training is constantly growing. The world's top athletes are roughly on a par in terms of fitness, and even a slight advantage in any aspect of it can prove decisive in securing victory. It is in this respect that technical training offers athletes the greatest potential for improvement, as its practical application and scientific underpinnings are still far from reaching their full potential (Deng et al., 2023; Czerwinski et al., 2015; Gavaa et al., 2015; Laputin, 1997; Schnabel, 1994).

The approaches and methods previously used to achieve outstanding victories and successes are not always applicable in modern sports training and do not meet the requirements for achieving winning and record-breaking results. Further improvement in sporting results is linked to addressing the issue of developing the technical skills of track and field jumpers and can be successfully achieved through the widespread application of theoretical principles and tools for a clear and effective system of monitoring the technical readiness of long

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jumpers (Bayraktar, 2023; Kolot, 2016; Kolot et al., 2025; Sovenko, 2023)..

In sports that require a high level of coordination, such as the long jump, an athlete's technical training and motor skills are of particular importance (Grosso, 2006; Kolot, 2005; Sovenko, 2022, 2025; Track and field, 2023).

An analysis of scientific and methodological literature and a review of best practice have shown that the development of technical skills among track and field jumpers is one of the key elements of training and ranks among the most pressing issues (Anderson et al., 2009; Bal et al., 2012; Martin, 1991; Schnabel, 1994).

There is currently a global trend towards improved performance in horizontal jumps, achieved by increasing the speed of the run-up prior to take-off. The speed attained by world-class jumpers during their run-up has reached a level comparable to that of sprinters. Consequently, the demands placed on take-off technique are increasing. As the take-off is executed in the long jump, there is a significant loss of horizontal velocity gained during the final metres of the run-up. Even among skilled athletes, the reduction in speed amounts to up to 1 $m \cdot s^{-1}$ (Bobrovnik, 2005; Kutek, 2015; Dornbusch & Liedtke, 2015). Consequently, further improvement in sporting performance is possible through the refinement of take-off technique as one of the key elements of the competitive event, provided that the speed gained during the run-up is retained as much as possible (Čoh et al., 1997; Horlov et al., 2019; Kolot, 2007; Schrapf, 2010).

The kinematic model of the long jump consists of four interdependent structural components: the run-up, the take-off, the flight phase and the landing. According to existing research, the run-up and the take-off are the most important factors influencing performance in the long jump. The fundamental problem in the long jump is the optimal conversion of the horizontal velocity, which the long jumper develops during the run-up, into vertical velocity during the take-off. Research findings demonstrate that the jump distance – in accordance with the kinematic model – will be determined by the GCMB height at take-off, the launch angle, the launch velocity, the take-off distance, the flight duration and the landing distance. The launch angle and launch velocity, which determine the GCMB's flight trajectory, in turn depend on the GCMB's horizontal and vertical velocity at the moment of take-off (Bobrovnik, 2005; Kolot, 2005; Kolot & Rezanov, 2025; Horlov et al., 2019; Kutek, 2015).

The development of sports science involves identifying general patterns in the manifestation of human potential during physical activity. However, to successfully apply these principles in the training of highly skilled long jumpers, it is necessary not only to understand the general patterns but also to take into account the individual characteristics of each athlete. General methodological principles that have a positive effect on a large group of athletes do not always prove effective at the individual level (Kolot & Rezanov, 2025; Track and field, 2023; Verkhoshasnky, 2012).

Experience in the field of sport shows that a great many talented athletes have left the sport without realising their full potential because they were subjected to a standardised training system that did not take sufficient account of their individual abilities, functional reserves and adaptive capacities. Therefore, one of the most promising approaches in the training of highly skilled athletes is the individualisation of training (Bobrovnik, 2005; Czerwinski et al., 2015; Gavaa et al., 2015; Laputin, 1997).

Differences in athletes' natural predisposition to the development of certain motor abilities, and the individual nature of the long-term training of top-class athletes, account for significant differences in the structure of sports training for highly skilled athletes at the stage of maximising their individual potential. To verify this theoretical and methodological proposition for highly skilled long jumpers in a competitive setting, a study was conducted on the inter-individual variability of athletes' technical readiness indicators.

Improving the effectiveness of athlete training at various stages of developing sporting skills depends largely on finding ways to optimise the management of the training process, making an informed choice of long jump technique, and selecting methods to refine the athlete's movements.

It is worth noting the inconsistency of practical recommendations regarding the improvement of technical proficiency among long jumpers of different ages and sporting levels, the need to take into account the specific characteristics of the long jumper's movement patterns during the run-up and the jump, as well as the failure of coaches to incorporate the latest achievements of sports pedagogy in the field of training process management using diagnostic methods based on real-time monitoring tools.

At the same time, the structure of the final steps of the run-up prior to take-off remains largely unexplored, and there is virtually no information regarding the dynamics of key performance indicators of take-off technique as athletic ability improves, nor their relationship with other biomechanical indicators of the long jump technique.

In light of the above, we believe that it is important to study and identify the characteristics of the take-off technique among jumpers of varying ability levels, as well as to determine the optimal biomechanical characteristics of the take-off in the long jump.

The aim of the study is to improve the technical proficiency of elite track and field athletes by establishing clear requirements for the individualisation of technical training for highly skilled long jumpers, taking into account the specific characteristics of the take-off technique and identifying the key components of technical readiness.

Tasks:

1. To identify the biomechanical characteristics of the take-off technique in the long jump among highly

skilled athletes.

2. To determine the optimal biomechanical characteristics of the take-off technique that help maintain the speed gained during the run-up.

Material & methods

Participants

The study involved long jumpers aged 20 and over who were at the peak of their individual performance (n = 32).

Procedure

The study was conducted between 2024 and 2025. During this phase of the research, a biomechanical analysis of the technique used in the competitive event was carried out. This was based on data obtained from video recordings we made of the Ukrainian Athletics Championships in 2024 and 2025, covering various age groups of male athletes.

Methods

To analyze the video images, the "Lumax" hardware-software complex was used (Ostrovskyi, 2003). Registration of athletes' body positions during the competitive exercise was carried out with Sony HDR-PJ50E video cameras at a speed of 50 $fp \cdot s^{-1}$.

All metrological requirements were taken into account during the research, which provided the correct placement of cameras and minimized systematic and random errors (Kolot, 2007; Sovenko, 2025). A human body model consisting of 20 points was used to digitize the movements of the athletes' body segments, following a defined digitisation sequence (Laputin, 1997).

Data on age and anthropometric characteristics of athletes (body length and weight) were obtained from the official website of the Athletics Federation of Ukraine, as well as during the survey at competitions.

Statistical analysis

Descriptive statistics indices were determined according to the level of results, kinematic characteristics of the technique, age, and anthropometric data: arithmetic mean ($\bar{x}$), standard deviation (S), and coefficient of variation (V). Licensed MS Excel software was used for the analysis.

Spearman and Pearson correlation coefficients were used to determine the relationships between the studied biomechanical parameters of long jump technique and their influence on the achievement of sports results, depending on the conformity of the data to the law of normal distribution. The conformity of the obtained data to the law of normal distribution was assessed using the Shapiro-Wilk conformity criterion at a significance level of $p=0.05$.

Statistical processing of the results by correlation analysis methods was performed using Statistica 14.0.0.15 software from StatSoft developers (TIBCO Software, USA).

Results of the study

An analysis of the competitive performance of highly skilled long jumpers identified three groups of athletes who, based on the individual structure of their take-off technique, can be classified as power-type, speed-type and all-round (speed-power) types (Tables 1–2 and Figure 1).

Table 1 shows that long jumpers who employ a power-based style of execution demonstrate the greatest activity during the take-off despite lower running-up speeds, as evidenced by the highest average take-off power, which for athletes of this type is 4.92 ± 0.19 kW. Athletes who demonstrate a power-style long jump technique make better use of their jumping and power abilities and perform an active take-off, which is evident in their thorough preparation for the take-off.

Preparation for take-off is characterised by greater joint absorption in the take-off leg (the minimum angle of flexion of the knee joint of the supporting leg during the take-off phase is smallest in power-type jumpers, at 138.78 ± 4.65 degrees). This is due to the strong forward extension of the take-off leg (the angle of the take-off leg placement in power-type jumpers is the smallest and amounts to 58.41 ± 2.43 degrees, which leads to a fairly significant deviation of the athlete's body from the vertical (the angle of the torso's deviation from the vertical at the take-off foot placement in power-type jumpers is the largest and amounts to -6.24 ± 2.18 degrees). Consequently, power-type long jumpers have the smallest take-off angle, which is 68.86 ± 2.11 degrees, forcing athletes to perform a more vertical take-off. In power-type athletes, the angle of the centre of mass (CM) is the greatest and amounts to 22.29 ± 0.61 degrees.

Due to lower velocity values in the joints of the take-off and swing legs, and a significant deviation of the torso from the vertical, power-type jumpers exhibit the largest values for the angles between the thighs when placing the foot on the take-off surface and when the foot leaves the support surface, which are 64.52 ± 3.46 degrees and 101.12 ± 6.32 degrees, respectively. Consequently, the range of motion of the push-off leg during the take-off is greatest in these athletes, amounting to 48.42 ± 2.48 degrees. This leads to an increase in the duration of contact with the support surface during the push-off and affects the duration of the push-off phase, which is longest in power-type athletes and amounts to 0.15 ± 0.01 s.

All-round athletes are well-proportioned and demonstrate both strength and speed components of their physical abilities, making full use of their speed-strength potential.

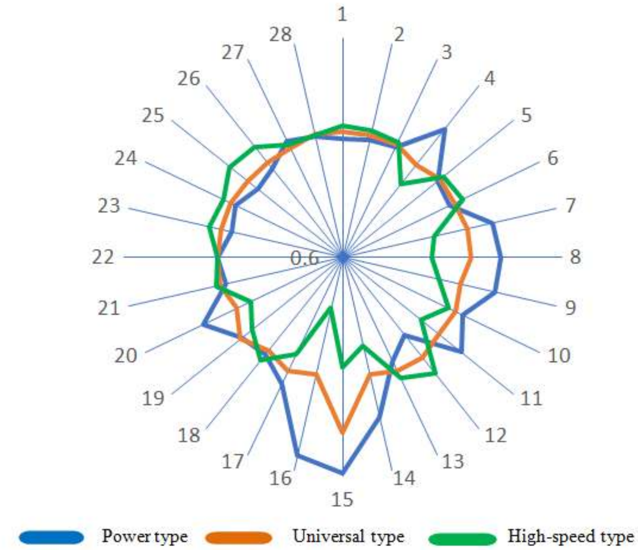
All-round athletes performing the long jump have higher running-up speeds than power-type athletes, and also demonstrate greater activity during the take-off phase, as characterised by the average take-off power. This figure is lower in all-round athletes than in power-type athletes, standing at 4.81 ± 0.17 kW, as the higher speed of movement prevents it from reaching its maximum value.

Table 1. Informative biomechanical angular and dynamic parameters that influence performance and determine individual take-off style in the long jump among men

Biomechanical parameter	Power type (n = 6)	Universal type (n = 6)	High-speed type (n = 6)
Body weight, kg	80.33±7.20	79.17±7.68	73.33±4.18
Athlete's height, cm	187.33±7.71	187.67± 6.74	189.00±2.83
Angle of the foot at push-off, deg.	58.41±2.43	64.26±3.08	68.46±1.04
The angle between the thighs when placing the foot for push-off, deg.	64.52±3.46	50.87±4.21	39.47±3.63
The angle of the torso's deviation from the vertical when placing the foot for the push-off, deg.	-6.24±2.18	-2.91±0.23	1.62±0.08
The minimum knee flexion angle of the support leg in the phase of take-off, deg.	138.78±4.65	141.66±5.36	144.66±3.76
The angle of departure, deg.	68.86±2,11	71.38±1,18	73.28±1,16
The angle between the thighs when the leg is lifted off the ground, deg.	101.12±6.32	96.72±4.82	90.84±5.18
The range of motion of the pushing leg during the push-off, deg.	48.42±2,48	42.37±2,15	38.34±2.08
The angle of departure of the GCMB, deg.	22.39±0.61	20.54±1.04	18.96±1.22
The duration of the take-off phase, s	0.15±0.01	0.13±0.01	0.12±0.01
The average power of take-off, kW	4.92±0,19	4.81±0,17	4.68±0,22
Result, m	7.43±0.04	7.46±0.03	7.44±0.04

Table 2. Informative kinematic and biomechanical parameters that influence performance and determine individual characteristics of the run-up in the long jump among men

Biomechanical parameter	Power type (n = 6)	Universal type (n = 6)	High-speed type (n = 6)
Body weight, kg	80.33 ± 7.20	79.17 ± 7.68	73.33 ± 4.18
Athlete's height, cm	187.33 ± 7.71	187.67 ± 6.74	189.00 ± 2.83
The angular velocity of the hip joint extension of the support leg during take-off, rad·s^{-1}	6.94 ± 0.06	7.04 ± 0.08	7.17 ± 0.07
The average horizontal velocity of swinging leg CM in the phase of take-off, m·s^{-1}	12.39 ± 0.31	12.48 ± 0.16	12.58 ± 0.28
The approach speed before take-off, m·s^{-1}	9.51 ± 0.14	9.62 ± 0.16	9.78 ± 0.36
The take-off speed of the GCMB at the moment of lift-off from the support, m·s^{-1}	8.72 ± 0.38	8.89 ± 0.18	9.13 ± 0.55
The loss of speed during take-off, m·s^{-1}, (%)	0.79 (8.31)	0.73 (7.59)	0.65 (6.65)
The vertical exit velocity, m·s^{-1}	3.71 ± 0.11	3.32 ± 0.18	3.09 ± 0.13
The length of the third step before take-off, m	2.39 ± 0.17	2.35 ± 0.11	2.44 ± 0.12
The length of the penultimate step before take-off, m	2.43 ± 0.22	2.44 ± 0.14	2.33 ± 0.18
The length of the final stride before take-off, m	2.46 ± 0.18	2.19 ± 0.15	2.08 ± 0.16
The running speed 5 m before take-off, m·s^{-1}, (%)	9.63 ± 0.07 (100)	9.82 ± 0.04 (100)	9.91 ± 0.05 (100)
The running speed 10 m before take-off, m·s^{-1}, (%)	9.03 ± 0.05 (93.8)	9.37 ± 0.49 (95.4)	9.72 ± 0.48 (98.1)
The running speed over the 20 metres leading up to the take-off, m·s^{-1}, (%)	8.42 ± 0.34 (87.4)	8.79 ± 0.39 (89.6)	9.43 ± 0.37 (95.2)
The take-off speed utilisation ratio, c.u.	0.77 ± 0.01	0.76 ± 0.01	0.75 ± 0.01
Result, m	7.43± 0.04	7.46 ± 0.03	7.44 ± 0.04



Note. Biomechanical characteristics of long jump technique:
1 – The minimum knee flexion angle of the support leg in the phase of take-off, deg.;
2 – The angular velocity of the hip joint extension of the support leg during take-off, rad·s^{-1};
3 – The average horizontal velocity of swinging leg CM in the phase of take-off, m·s^{-1};
4 – The duration of the take-off phase, s;
5 – The approach speed before take-off, m·s^{-1};
6 – The take-off speed of the GCMB at the moment of lift-off from the support, m·s^{-1};
7 – The loss of speed during take-off, m·s^{-1};
8 – The loss of speed during take-off, %;
9 – The vertical exit velocity, m·s^{-1};
10 – The average power of take-off, kW;
11 – The angle of departure of the GCMB, deg.;
12 – Angle of the foot at push-off, deg.;
13 – The angle of departure, deg.;
14 – The range of motion of the pushing leg during the push-off, deg.;
15 – The angle between the thighs when placing the foot for push-off, deg.;
16 – The angle between the thighs when placing the foot for push-off, deg.;
17 – The angle between the thighs when the leg is lifted off the ground, deg.;
18 – The length of the third step before take-off, m;
19 – The length of the penultimate step before take-off, m;
20 – The length of the final stride before take-off, m;
21 – The running speed 5 m before take-off, m·s^{-1};
22 – The running speed 5 m before take-off, %;
23 – The running speed 10 m before take-off, m·s^{-1};
24 – The running speed 10 m before take-off, %;
25 – The running speed over the 20 metres leading up to the take-off, m·s^{-1};
26 – The running speed over the 20 metres leading up to the take-off, %;
27 – The take-off speed utilisation ratio, c.u.;
28 – Result, m.
Fig. 1. Biomechanical parameters determining individual take-off style in the long jump among men

All-round athletes make better use of their speed and strength capabilities and also perform an active take-off, which is characterised by less preparation for this phase of the long jump. Preparation for the take-off is reflected in less deep cushioning in the joints of the take-off leg (the minimum angle of flexion of the knee joint of the supporting leg during the take-off phase is greater in all-round jumpers than in power-type jumpers, and amounts to 141.66 ± 5.36 degrees). This is due to the take-off leg being positioned further forward (the angle of foot placement at take-off in universal-type jumpers is greater than in power-type athletes, and amounts to 64.26 ± 3.08 degrees), which leads to a smaller deviation of the athlete's body from the vertical (the angle of the torso's deviation from the vertical when placing the foot for take-off in universal-type jumpers is -2.91 ± 0.23 degrees). Consequently, universal (speed-power) type long jumpers have a greater take-off angle than power-type athletes, amounting to 71.38 ± 1.18 degrees, which facilitates a more horizontal take-off. In universal-type athletes, the angle of the centre of mass trajectory is smaller than in power-type athletes, and amounts to 20.54 ± 1.04 degrees.

Due to higher speeds in the joints of the take-off and swing legs, and a slight deviation of the torso from the vertical, all-round jumpers exhibit smaller hip angles when placing the take-off foot and when the foot leaves the support, which are 50.87 ± 4.21 degrees and 96.72 ± 4.82 degrees, respectively. Consequently, the range of motion of the push-off leg during the take-off is reduced in these athletes and amounts to 42.37 ± 2.15 degrees. This leads to a reduction in the duration of contact with the ground during the push-off and contributes to a shorter push-off phase, which in athletes of the universal (speed-strength) type is 0.13 ± 0.01 s.

Speed-type long jumpers have the highest running speeds, which prevents them from generating a powerful take-off. The average take-off power among these athletes is the lowest, at 4.68 ± 0.22 kW.

Athletes who demonstrate a speed-oriented style of long jump make better use of their jumping and speed abilities and execute a rapid take-off, which is evident in the almost complete absence of a preparatory phase before take-off. Preparation for the take-off is characterised by minimal cushioning in the joints of the take-off leg (the minimum angle of flexion of the knee joint of the supporting leg during the take-off phase is greatest in speed-type jumpers and amounts to 144.66 ± 3.76 degrees). This is due to the take-off leg being positioned almost directly beneath the body (the angle of the take-off leg placement in speed-type jumpers is the greatest and amounts to 68.46 ± 1.04 degrees), which leads not to deflection, but to a forward tilt of the torso relative to the vertical (the angle of the torso's deviation from the vertical when placing the take-off foot is smallest for speed-type jumpers, has a positive value and amounts to 1.62 ± 0.08 degrees). Consequently, speed-type long jumpers perform an almost running take-off and have the largest take-off angle, which is 73.28 ± 1.16 degrees, forcing athletes to make a more horizontal take-off. In speed-type athletes, the angle of the centre of mass (CM) is the smallest and amounts to 18.96 ± 1.22 degrees.

Due to higher speeds in the joints of the take-off and swing legs and the almost complete absence of trunk deviation from the vertical, speed-type jumpers have the smallest angles between the thighs when placing the foot on the take-off surface and when the foot leaves the support, which are 39.47 ± 3.63 degrees and 90.84 ± 5.18 degrees, respectively. Consequently, the range of motion of the push-off leg during the take-off is the smallest in these athletes, amounting to 38.34 ± 2.08 degrees. This leads to a significant reduction in the duration of contact with the ground during the push-off and affects the duration of the push-off phase, which is shortest in speed-type athletes and amounts to 0.12 ± 0.01 s.

An analysis of the competitive performance of highly skilled long jumpers revealed differences in speed and rhythm characteristics, as well as individual variations in the approach run among athletes practising the power, all-round (speed-power) and speed styles of the long jump (Table 2).

If one examines the change in the length of the last three steps taken by power-style long jumpers, it can be seen that the length of the steps increases from the third to the last, with the final step being the longest at 2.46 ± 0.18 m. This is due to the far placement of the take-off leg and a significant deviation of the torso from the vertical. As a result, power-type athletes have to perform a more vertical take-off, which generates maximum vertical velocity, which for these jumpers is 3.71 ± 0.11 $m \cdot s^{-1}$. Consequently, the run-up speed before take-off (9.51 ± 0.14 $m \cdot s^{-1}$) and the exit velocity of the centre of mass at the moment of leaving the ground (8.72 ± 0.38 $m \cdot s^{-1}$) are the lowest among long jumpers using a power-style technique, whilst the loss of speed during the take-off is the greatest (0.79 $m \cdot s^{-1}$), amounting to 8.31 %. This reduces the speed and activity of the joints in the take-off and swing legs, as evidenced by the minimal values of the angular velocity of hip joint extension in the supporting leg during the take-off from the support (6.94 ± 0.06 $rad \cdot s^{-1}$) and the average horizontal velocity of the centre of mass of the swing leg during the take-off phase (12.39 ± 0.31 $m \cdot s^{-1}$).

It was found that jumpers of all types reach their maximum take-off speed 5 metres before take-off. For power-type athletes, this figure is 9.63 ± 0.07 $m \cdot s^{-1}$ (100 %). The take-off speed 10 m before take-off for power-type jumpers is 9.03 ± 0.05 $m \cdot s^{-1}$, which is 93.8 % of the maximum. The run-up speed 20 m before take-off for power-type jumpers is 8.42 ± 0.34 $m \cdot s^{-1}$, which is 87.4 % of the maximum. It can be observed that power-style long jumpers have the lowest speed values across all sections of the run-up. This prevents them from fully utilising their run-up speed to achieve the desired result, as evidenced by the run-up speed utilisation coefficient (the ratio of the result to the maximum run-up speed), which stands at 0.77 c.u. for power-type athletes.

Athletes who use a versatile (speed-power) style of long jump have a different pattern of movement in the final three steps of the run-up. For universal-type jumpers, the length of the third step before take-off is 2.35 ± 0.11 m. The length of the penultimate step before take-off in these athletes increases slightly due to the crouch and preparation for take-off, and amounts to 2.44 ± 0.14 m. The length of the final step before take-off in all-round jumpers is significantly reduced due to the active, short placement of the take-off leg and a slight deviation of the torso from the vertical. As a result, all-round jumpers perform a more horizontal take-off, generating a vertical velocity of 3.32 ± 0.18 $m \cdot s^{-1}$. Consequently, the run-up speed before take-off (9.62 ± 0.16 $m \cdot s^{-1}$) and the exit velocity of the centre of mass at the moment of leaving the ground (8.89 ± 0.18 $m \cdot s^{-1}$) are higher in universal-style long jumpers than in power-type athletes, whilst the loss of speed during the take-off is lower (0.73 $m \cdot s^{-1}$), amounting to 7.59 %. This increases the speed and activity of movements in the joints of the take-off and swing legs, as evidenced by higher values of the angular velocity of hip joint extension in the supporting leg during the take-off phase (7.04 ± 0.08 $rad \cdot s^{-1}$) and the average horizontal velocity of the centre of mass of the swing leg during the take-off phase (12.48 ± 0.16 $m \cdot s^{-1}$).

For all-round athletes, the running speed 5 m before take-off is 9.82 ± 0.04 $m \cdot s^{-1}$ (100 %). The run-up speed 10 m before take-off for all-round jumpers is 9.37 ± 0.49 m·s⁻¹, which is 95.4 % of the maximum. The run-up speed 20 m before take-off for all-round jumpers is 8.79 ± 0.39 m·s⁻¹, which is 89.6 % of the maximum. It can be observed that all-round long jumpers have higher speed values across all sections of the run-up than power-type jumpers. This allows for better utilisation of run-up speed to achieve results, as evidenced by the run-up speed utilisation coefficient, which stands at 0.76 c.u. for all-round athletes.

If one observes the change in the length of the last three strides taken by speed-style long jumpers during the jump, it can be seen that the stride length decreases from the third to the last stride, with the final stride being the shortest at 2.08 ± 0.16 m. This is due to the take-off leg being positioned almost directly beneath the body and the absence of any deviation of the torso from the vertical, or only a slight forward lean. As a result, speed-type athletes perform a more horizontal take-off, which generates vertical velocity, which is the lowest vertical velocity among these jumpers, at 3.09 ± 0.13 m·s⁻¹. Consequently, the run-up speed before take-off (9.78 ± 0.36 m·s⁻¹) and the exit speed of the centre of mass at the moment of leaving the support (9.13 ± 0.55 m·s⁻¹) are highest among speed-type long jumpers, whilst the loss of speed during the take-off is the lowest (0.65 m·s⁻¹), amounting to 6.65%. This increases the speed and activity of movements in the joints of the take-off and swing legs, as evidenced by the maximum values of the angular velocity of hip joint extension in the supporting leg during the take-off from the support (7.17 ± 0.07 rad·s⁻¹) and the average horizontal velocity of the centre of mass of the swinging leg in the take-off phase (12.58 ± 0.28 m·s⁻¹).

For speed-type athletes, the running speed 5 m before take-off is 9.91 ± 0.05 m·s⁻¹ (100 %). The running speed 10 m before take-off for speed-type jumpers is 9.72 ± 0.48 m·s⁻¹, which is 98.1 % of the maximum. The running speed 20 m before take-off for speed-type jumpers is 9.43 ± 0.37 m·s⁻¹, which is 95.2 % of the maximum. It can be observed that speed-type long jumpers have the highest speed values across all sections of the run-up compared to power-type and all-round jumpers. This allows them to maximise the realisation of run-up speed to achieve the result, as evidenced by the run-up speed realisation coefficient, which stands at 0.75 c.u. for speed-type athletes.

Discussion

Tables 3 and 4 present the qualitative kinematic and dynamic characteristics of the take-off styles of highly skilled long jumpers. It can be seen that athletes with a power-type long jump technique, due to the far placement of the push-off leg during take-off, have a wide stance and a small angle at the knee joint during foot placement and lift-off, which prevents them from performing a steeper vertical take-off. As a result, there is a significant loss of horizontal velocity, but vertical velocity and take-off power increase considerably.

Table 3. Classification of take-off types among elite long jumpers based on qualitative kinematic characteristics

Types of push-off	A jumping movement of the leg	The angle at the knee joint, depending on the starting position
Power type	Characterised by a dominant vertical movement: a significant change in the angle of the knee joint as the leg lifts off the ground (slight 'stiffness' in the pushing leg)	Wide stance, slight bend in the knee when planting and lifting the foot, powerful push-off
Universal type	It is characterised by a predominantly horizontal movement: a slight change in the angle of the knee joint as the leg lifts off the ground (stiff ankle)	A narrow stance, a wide angle at the knee joint when planting and lifting the foot, and a powerful push-off
High-speed type	It is characterised by a very pronounced horizontal movement: there is little change in the angle of the knee joint when the foot is lifted off the ground (stiff ankle)	Narrow stance, low lift, large angle at the knee joint during the landing and take-off phases, flat push-off

Table 4. Classification of take-off types among elite long jumpers based on qualitative dynamic characteristics

Types of push-off	Loss of horizontal speed	Loss of vertical velocity	Repulsive force
Power type	A significant loss of horizontal speed	A significant increase in vertical velocity	A significant increase in repulsion force
Universal type	A moderate or slight loss of horizontal speed	Average increase in vertical velocity	Average increase in take-off power
High-speed type	A slight loss of horizontal speed	A slight increase in vertical velocity	A slight increase in thrust

Athletes with a versatile long jump technique, due to placing their take-off foot relatively closer to beneath the body, have a narrow stance and a large angle at the knee joint when setting up and lifting the leg, which forces them to perform a similarly steep but more horizontal take-off. This results in a moderate or slight loss of horizontal velocity, leading to a moderate increase in vertical velocity and take-off power.

Athletes who use a speed-oriented technique for the long jump, placing their take-off foot almost directly beneath them, adopt a narrow stance and a large angle at the knee joint during foot placement and take-off, which forces them to execute a flatter horizontal take-off. This results in a small loss of horizontal speed, but at the same time, vertical speed and take-off power increase only slightly.

Using the computer programme we developed for processing and analysing athletes' movement techniques, it has become possible for the first time to conduct a biomechanical analysis of 58 kinematic and dynamic characteristics of the long jump and to identify those that determine the achievement of high sporting results. The data obtained formed the basis for determining the optimal composition of exercise groups with different training emphases, aimed at improving and maximising the specialised technical readiness of highly skilled long jumpers within the annual training cycle.

As a result of research conducted using modern equipment for recording and analysing athletes' movements, it has been established for the first time that performance in the long jump and individual technique in the take-off and run-up depend on the following factors: the angle of the take-off foot, the angle between the thighs at the moment the take-off foot is planted, the angle of the torso's deviation from the vertical when the foot is placed on the take-off surface, the minimum angle of flexion of the supporting leg's knee joint during the take-off phase, the take-off angle, the angle between the thighs when the foot leaves the support surface, the amplitude of movement of the take-off leg during take-off, the angle of the centre of mass (CM) take-off, the duration of the push-off phase, the average push-off power, the angular velocity of hip joint extension of the supporting leg during the push-off from the support, the average horizontal velocity of the centre of mass of the swing leg during the push-off phase, the run-up speed prior to push-off, the exit velocity of the centre of mass at the moment of foot lift-off, the loss of velocity during push-off, the vertical exit velocity, the length of the third step prior to push-off, the length of the penultimate step before take-off, the length of the final step before take-off, the running speed 5 m before take-off, the running speed 10 m before take-off, the running speed 20 m before take-off, and the running speed realisation coefficient.

The data obtained during the experiment do not contradict the findings of previous studies conducted in this field by Ukrainian and international experts (Akhmetov et al., 2016; Bobrovnik, 2005; Horlov et al., 2019; Makaruk et al., 2015), but there are still minor discrepancies in the quantitative characteristics of the speed of the mid-stride phase in the run-up before take-off and in the angular characteristics, attributable to differences in the measurement equipment used across studies. Another reason is that biomechanical analysis of the long jump technique is predominantly carried out on elite athletes, whose level of specialised training is much higher than that of long jumpers in Ukraine, and whose individual biomechanical profiles may differ from those of the athletes studied here.

The angular velocity of knee extension in the supporting leg plays a significant role in achieving high performance in the long jump ($r = -0.41$); an increase in this value indicates the ability to make greater use of the elastic properties of muscles and tendons during the take-off, as evidenced by the findings of this study. Similar findings have been reported by other specialists who conducted studies involving top-class long jumpers (Bobrovnik, 2005; Kolot, 2007; Kolot & Rezanov, 2025).

The higher a long jumper's level of athletic skill, the less variation there is in the angular characteristics of these joints during the take-off phase, as modern long jump technique is characterised by optimal flexion angles in the knee and hip joints. This is linked to a reduction in the shock-absorption phase during the take-off, due to increased stiffness in the knee and hip joints, which significantly increases the importance of the duration of the take-off phase ($r = -0.72$). During the push-off, there is a marked increase in the role of joint movements and the work of the muscles involved in generating vertical take-off velocity. For an effective push-off, the flexor muscles of the ankle joint play a leading role in generating force by utilising the energy of elastic deformation. As long jump performance improves, the duration of contact with the ground decreases. This is consistent with the findings of other authors (Bobrovnik, 2005; Rozhkov et al., 2024; Scherrer et al., 2022; Sutula & Yang Jin Tian, 2002) and is confirmed by experimental data indicating that the angular velocity of hip flexion in the swing leg during the take-off phase plays a significant role in achieving high sporting performance among elite long jumpers. Previously, there were only a few publications on the influence of the swing leg's speed on athletic performance in the long jump (Bobrovnik, 2005). These discussed the leading role of swing movements in the coordination of long jumpers' movements during the take-off phase.

A computer programme for processing and analysing human movement has, for the first time, made it possible to objectively quantify the least-studied technical parameters of the long jump – average power, the athlete's total energy during take-off, and others. The higher the take-off power, the better the result in the long jump ($r = 0.99$). This conclusion is based on the finding that there is a close correlation between high sporting performance and the power developed by long jumpers at the moment of take-off.

The authors of some literature sources, which state that the take-off in the long jump is performed with elasticity and power, do not provide quantitative values for this parameter (Schrapf, 2010; Sutula & Yang Jin Tian, 2002; Track and Field, 2023). We have established that improvements in long jump performance are linked to the potential for increasing take-off power, which is enhanced both by the force of interaction with the take-off board and by a reduction in take-off time, and is of an individual nature (Bobrovnik, 2005; Kolot, 2007; Kolot & Rezanov, 2025).

Our research findings confirm that performance in the long jump depends on the speed of the run-up prior to take-off ($r = 0.88$) (Bobrovnik, 2005; Coh et al., 1997; Horlov et al., 2019; Sutula & Yang Jin Tian, 2002).

Our study has established a strong correlation between the long jump result and the take-off speed at the moment of leaving the ground ($r = 0.91$) and the take-off angle during the push-off ($r = 0.60$), a finding supported by a number of studies by other authors (Bobrovnik, 2005; Coh et al., 1997; Dornbusch & Liedtke, 2015). In our opinion, it is advisable to increase the distance of the long jump by reducing speed loss during the take-off and increasing take-off velocity. Increasing the distance of the long jump by altering the take-off angle is less promising. The authors of the studies (Coh et al., 1997; Horlov et al., 2019; Sutula & Yang Jin Tian, 2002) point to the limited potential for increasing the long jump distance by altering the take-off angle due to the latter's lower variability, and consider that improving long jump performance is possible by increasing take-off speed during the take-off phase alongside a significant increase in muscle strength.

It has been established for the first time that high sporting performance is linked to a reduction in body mass among long jumpers, as evidenced by the findings of this study. According to current understanding, a reduction in body weight reduces the effect of gravity, which can have a positive impact on sporting performance. As body weight increases, so do the forces of gravity; therefore, to overcome them, greater effort must be exerted during the take-off. However, a reduction in body mass entails changes in the biomechanical characteristics of the long jump technique and a restructuring of the movement pattern as a whole (Bobrovnik, 2005; Kolot, 2007; Kolot & Rezanov, 2025). From this perspective, a sharp reduction in body mass prior to the start may have a negative impact on achieving high sporting results in the season's major competitions.

Conclusions

1. Thus, the video motion analysis system we used enabled us to analyse the biomechanical characteristics of the running long jump technique and identify those factors that determine the achievement of high sporting results.

2 The key technical characteristics of the take-off phase that influence the result of the long jump have been identified, with a focus on minimising speed loss from the run-up.

3. These indicators can serve as objective criteria for assessing the technical readiness of skilled long jumpers.

4. A well-structured training programme requires a clear focus on developing an optimal structure for competitive performance, ensuring effective competition tactics and the achievement of the desired model of competitive performance. This is only possible if one has a clear understanding of the factors that determine effective competitive performance, as well as the relationship between the structure of competitive performance and physical readiness.

Conflict of interest

The author(s) declared no conflict of interest concerning this work, authorship, and/or publications of this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors didn't use any AI tool in the preparation or writing of the article.

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