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Original Article

Characteristics of the technical action model for athletes specializing in race walking within the long-term development system

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Abstract:
At the current stage of sports development, technical training within the long-term improvement system for race walking athletes should involve clearly defined model characteristics of their technical actions. The integration of advanced modeling technologies, such as artificial neural networks, allows for the creation of effective and high-quality models that represent athletes' technical actions. Objective: To improve the technical preparation of track-and-field athletes specializing in race walking by identifying model characteristics of technical actions within a long-term preparation framework. Materials and Methods: Neural network modeling of the technical actions of athletes specializing in race walking was performed based on data from biomechanical analyses of competitive exercise techniques. This data was collected via video recordings during the 2014–2021 Ukrainian Race Walking Championships, as well as at the Association of Balkan Athletic Federations Championships and the international "Evening Ivano-Frankivsk" Cup, organized in conjunction with Ukraine's national championships. The studies included male athletes from various age groups competing at distances of 3 km, 10 km, and 20 km. In total, 98 analyses were conducted: 31 at 3 km, 36 at 10 km, and 31 at 20 km. Results. A total of 26 biomechanical indices of athletes' techniques were analyzed. Correlation analysis identified 14 key biomechanical characteristics that significantly influence performance outcomes within the long-term development system. Using these characteristics, along with indices of body length and mass, neural network models were developed to simulate and predict athletic performance. Conclusions. Artificial neural networks enabled the creation of models for race-walking technical actions that support high-level performance in young athletes aged 13–15 years (3 km distance), boys aged 16–19 years (10 km distance), and elite athletes aged 20 years and older (20 km distance).
Keywords: long-term preparation, modeling, neural networks, technical actions, race walking.

Introduction

The current state of race walking development is characterized by a steady increase in the level of results and competition at the Olympic Games and World Championships.

At the same time, it should be noted that the struggle for the highest places on the podiums of the world's largest forums continues until the last meters of the distance. It should not go unmentioned that the ability to increase speed by the end of the distance is a characteristic feature of the competitive activity of the medalists of the world's largest forums. The ability to cover the second part of the distance at a speed higher than the overall average is a distinguishing feature of the prize-winners of the World Championships and the Olympic Games (Hanley et al., 2008; Kisiel K. & Kisiel J., 2017; Sovenko, 2020). For instance, the winner of the 2024 Olympic Games in Paris at a distance of 20 km, Brian Daniel Pintado from Ecuador, covered the last four kilometers at a speed of 4.47 $m \cdot s^{-1}$, which is higher than the average speed of covering the distance by Yusuke Suzuki from Japan (4.35 $m \cdot s^{-1}$) when he set the world record.

At the same time, the requirements for the level of athletes' fitness are growing, which necessitates constant improvement of training methods not only for top-level but young athletes as well (Platonov, 2015; Sovenko, 2022).

One of the priority directions for improvement of the modern system of long-term preparation of athletes is the optimization of their technical training, which in harmonious combination with physical training will allow them to achieve high sports results at the optimal age and further maintain high sportsmanship for many years (Bobrovnyk & Sovenko, 2024; Vinogradova & Sovenko, 2020).

It is important to emphasize that the improvement of technical actions is a complex multi-year process envisaging the solution of relevant tasks at each stage of long-term preparation. Therefore, it is effective to consider the process of improving technical actions comprehensively in the system of long-term preparation.

Today, with the creation of modern technologies of biomechanical control, it is possible to manage technical training quickly and efficiently in the process of improving the technical skills of athletes. Among the

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components of the modern system of technical training management, the process of modeling the technical actions of athletes assumes special interest (Shynkaruk & Serebriakov, 2021) as far as an important function of the models is their significant contribution to the translation of scientific research results into sports practice (Platonov, 2015).

One of the priority areas for improving sports techniques is the method of computer modeling (Bobrovnyk & Sovenko, 2024).

Describing the issues in the existing traditional methods of modeling and forecasting, J. Wang (2021) argues that the future lies in the development according to a method that involves the use of neural networks characterized by an unessential error, does not require significant physical efforts in operation, and is marked by low technical requirements. H. Zhao et al. (2023) share the same view based on comparing data obtained from neural networks and linear multiple regression models.

Therefore, it is no coincidence that today neural networks are increasingly being used in sports in various areas of modeling and forecasting: the level of sports results (Zhao et al., 2023), technical actions of athletes (Imas et al., 2018), training of athletes (Li X. & Li Y., 2022; Guo et al, 2024), tracking the athlete's body movement based on video recording (Li et al., 2022; Khmelnitska et al., 2024; Li, Guo, Huang, 2022), and various sensors (Li & Wu, 2023), prevention and detection of injuries (Shaos et al, 2022; Meng & Qiao, 2021; Wen, 2021) and risks in sports (Li et al., 2023), organization of mass-scale sports events (Wang & Wang, 2022; Zhong et al., 2022).

Similar studies are beginning to be conducted in race walking as well. For instance, K. Wiktorowicz et al. (2015) developed effective models for predicting sports results based on training process data. They used both regression (linear and nonlinear) models and those developed by artificial neural networks.

However, we failed to find any studies on modeling the technical actions of athletes specialized in race walking in the system of long-term preparation using neural networks in the available literature. At the same time in the scientific and methodical literature in the works dealing with the analysis of race walking techniques K. Hoga-Miura et al. (2006; 2022), B. Hanley et al. (2008; 2014; 2019; 2020), J. Broďani et al. (2011), G. Pavei et al. (2014, 2019) and others have laid the foundations for solving this problem.

The objective of the study is to improve the technical training of athletes specialized in race walking by determining the model characteristics of technical actions in the system of long-term preparation.

Material & methods

Participants

The biomechanical analysis of a competitive exercise technique performance was carried out based on data obtained during the video recording of the Ukrainian race walking championships of 2014-2021, as well as at the Association of Balkan Athletics Federations championships, and “Evening Ivano-Frankivsk” Cup international race walking competitions organized together with the national championships of Ukraine, in different age groups of males (n = 89), including at distances of 3 km (n = 31), 10 km (n = 36), and 20 km (n = 31).

Procedure

As far as the length of competitive distances differed in athletes of different age groups, video recording and further biomechanical analysis were carried out on the following segments: 20 km distance - 5, 10, 14, and 18 km (only in 2014 it was determined on three segments of the distance: 2, 10, and 18 km); 10 km distance - 2, 5, and 8 km; 3 km distance - 1 and 2 km, 2 km distance - 1 km. In general, taking into account the number of studied biomechanical indices of technique 26, about 5,000 measurements were analyzed regarding the characteristics of the technique of athletes specialized in race walking in the system of long-term preparation.

The video image was analyzed by the hardware and software complex “Lumax” (Sovenko, 2020).

The registration of the body positions of athletes during a competitive exercise performance was made by video cameras “Sony DCR-SR 65” at a speed of 25 frames·s^{-1} with the subsequent division into 50 half-frames·s^{-1} (2014-2015) and a video camera “Sony HDR-PJ50E” at a speed of 50 frames·s^{-1} (2016-2021).

All metrological requirements were taken into account during the research, which allowed for proper camera placement and minimization of systematic and random errors. A human body model consisting of 20 points plotted in clear sequence was used to digitize the movements of the athletes' bio-links.

Data on the age and anthropometric characteristics of athletes (body length and mass) were obtained from the official website of the Ukrainian Athletics Federation (Statistics UAF).

Statistical analysis. The correlation coefficients of Spearman and Pearson were applied to determine the presence or absence of interrelation between the studied biomechanical indices of race walking technique and their influence on the achievement of a sports result, depending on data conformity to the law of normal distribution. The consistency of the obtained data to the normal distribution law was estimated by using the Shapiro-Wilk goodness-of-fit test.

Statistical processing of the results by methods of correlation analysis, as well as modeling with artificial neural networks, was carried out using Statistica 14.0.0.15 software from StatSoft (TIBCO Software, USA).

Results

In total, 26 biomechanical characteristics of athletes' technique were analyzed as a result of the conducted research on race walking technique at the stages of preliminary basic preparation (13-15 years old; 3 km distance, n=31), specialized basic preparation (16-19 years old; 10 km distance, n=36), and in highly skilled athletes from the stage of preparation for higher achievements to that of high sports mastery preservation (20 and more years old; 20 km distance, n=31). Based on the correlation analysis 14 informative biomechanical characteristics of athletes were identified in the system of long-term preparation, which affect the achievement of sports result (Table 1).

Table 1. Anthropometrical data and informative biomechanical characteristics of race walking technique in men and their interrelation with sports result in the system of long-term preparation

Index	Stage* of long-term preparation (age years), distance, number of studies		
	PHA, MRIC, HSMP (20 & more), 20 km (n=31)	SBP (16–19), 10 km (n=36)	PBP (13–15), 3 km (n=31)
Body length, m	0.19	0.07	-0.17
Body mass, kg	-0.19	0.06	-0.24
Stride length, m	**-0.61**	**-0.64**	**-0.76**
Rear stride length, m	-0.15	0.15	**-0.45**
Flight length, m	**-0.55**	**-0.74**	**-0.68**
Front stride length, m	-0.23	0.20	-0.02
The length of the support (foot) transition, m	0.22	-0.11	0.05
Stride frequency, stride·s^{-1}	**-0.70**	**-0.63**	0.01
Single support time, s	**0.63**	**0.75**	**0.39**
Absorption time in the single support phase, s	**0.41**	**0.61**	**0.48**
Realization time in the single support phase, s	**0.48**	**0.64**	0.05
Flight time, s	-0.09	**-0.79**	**-0.55**
The knee joint angle at the moment of foot placing on the support, deg.	-0.20	**-0.36**	0.13
The knee joint angle at the moment of verticality, deg.	**-0.48**	**-0.48**	-0.21
Ka - the ratio of stride length to body length, conv. un.	**-0.75**	**-0.51**	**-0.72**
The speed of movement of the BGCM at the moment of foot placing on the support, m·s^{-1}	**-0.69**	**-0.92**	**-0.94**
The speed of movement of the BGCM at the moment of foot detachment from the support, m·s^{-1}	**-0.92**	**-0.95**	**-0.95**
Amplitude of the shoulder joint movement (of ipsilateral limb) in the phase of single support, m	**-0.78**	**-0.59**	**-0.70**
Amplitude of the hip joint movement of the swinging leg in the phase of single support, m	**-0.80**	**-0.55**	**-0.68**
Angle of foot placing on a support, deg.	**0.37**	-0.24	0.22
The angle of take-off, deg.	**0.63**	0.19	0.17
Angular velocity of the hip joint of the swinging leg flexion in the phase of single support, rad·s^{-1}	**-0.53**	**-0.80**	**-0.73**
Angular velocity of the knee joint of the swinging leg extension in the phase of a single support, rad·s^{-1}	**-0.59**	**-0.88**	**-0.84**
Angular velocity of the elbow joint (of ipsilateral limb) extension-flexion in the phase of a single support, rad·s^{-1}	-0.34	-0.21	-0.32
Angular velocity of a shoulder joint (of ipsilateral limb) flexion in a phase of a single support, rad·s^{-1}	**-0.36**	**-0.33**	**-0.39**
Resultant force of support reaction in the phase of a single support, N	**-0.58**	**-0.83**	**-0.89**
Take-off power in the phase of single support, W	**-0.78**	**-0.92**	**-0.95**
Ke - the ratio of power to stride length per kilogram of body mass, conv.un.	**-0.39**	0.29	0.35

Notes. Stages: PHA - preparation for higher achievements, MRIC - maximum realization of individual capabilities, HSMP - high sports mastery preservation, SBP - specialized basic preparation, PBP - preliminary basic preparation. Informative biomechanical indices are highlighted in bold

As Table 1 shows, the achievement of high sports results in race walking depends on the following kinematic and dynamic characteristics of athletes' technical actions: stride length and frequency, duration of single support phase, coefficient of use of anthropometric data, speed of movement of the BGCM at the moment of foot placing on the support and at the moment of foot detachment from the support, the amplitude of movement of the shoulder joint (of ipsilateral limb) and the hip joint of the swinging leg in the phase of single support, the angular velocity of flexion of the hip joint of the swinging leg and extension of the knee joint of the swinging leg in the phase of single support, the resultant force of the support reaction and the power of take-off in the phase of single support, angular velocity of the shoulder joint (of ipsilateral limb) flexion in the phase of single support. Although we did not find a high correlation of sports result with the index of take-off power to stride length ratio at the stages of long-term preparation, we included it in further research, as it characterizes the economy of movements, which can be traced in its dynamics during the level of athletes' skill increase in the process of long-term improvement. It is noteworthy that neither in men nor in women a statistically significant relationship between sports result and body length and mass was revealed at almost all stages of long-term preparation. However, these indices correlate with other system-forming biomechanical characteristics of technique, which have statistically significant interrelation with sports result. Therefore, they should be taken into account in the future, when analyzing and modeling the technique of athletes.

The next stage was to create models of the main elements of athletes' technical actions at the stages of long-term improvement. The input data were 14 informative biomechanical characteristics of the athletes' technique and their anthropometric data (body length and mass), whereas the sports results represented the output data. However, in order for an artificial neural network to model or predict a sports result, it needs to be trained. This is the main difference and advantage of neural networks compared to traditional algorithms.

In the process of training, a neural network is able to detect complex dependencies between input and output data, as well as to make generalizations. Therefore, the better the relevant input data reflects the trends in the output data changes, the better the training and, thus, the more accurate the model. However, we have obtained biomechanical and anthropometric characteristics of athletes, both in men at the stages of preliminary basic (13-15 years old), specialized basic preparation (16-19 years old) and highly skilled athletes, beginning from the stage of preparation for higher achievements and ending with the stage of high sports mastery preservation (20 years and more). For each of these contingents, a model of technical actions was created, which was trained on the corresponding contingent. It should be noted that all basic data provided rather high efficiency of training, however the greatest accuracy was demonstrated by models, training of which was based on the data obtained on highly skilled athletes at the stages of preparation for higher achievements, maximum realization of individual capabilities, and high sports mastery preservation. Thus, the mean square error when using this model on all the presented contingents of athletes did not exceed 0.4 %. The correctness of this chosen approach in training neural networks can be theoretically substantiated. In particular, the contingent of young athletes in the first stage of long-term development at the stages of preliminary and specialized basic preparation is characterized by rapid and asymmetrical periods of anthropometric characteristics development, uneven pedagogical influence on the development of physical qualities and technical fitness, etc., which affects the search for clear regularities of sports results increase. Let us consider the procedure of choosing the most effective model of technique on the material of highly skilled athletes specialized in race walking. It should be noted that the corresponding procedure was previously applied using the same algorithm on each data block, i.e. on three variants depending on the stage of long-term preparation. At the same time, the obtained models were also saved in the database, since they were highly reliable and can also be used as a supplement during modeling of athletes' technique. In developing an effective model, the multilayer neural networks with direct information transfer of two types - multilayer perceptron (MLP) and radial basis function (RBF) were used. The configuration of the obtained networks for modeling the technique of race walking included 16 neurons (14 biomechanical characteristics and 2 anthropometric) of the input layer. The number of neurons in the hidden layer of the obtained neural networks ranged from 5 to 16. The output neuron was an indicator of sports result.

During the modeling process, we obtained 12 neural networks (Table 2).

Table 2. Neural networks of race walking technique

Network number	Network title	Network characteristics								
		Efficiency			Error			Training algorithm	Activation function	
		Training	Control	Testing	Training	Control	Testing		Hidden neurons	Output neurons
1.	MLP 16-12-1	0.999700	0.999952	0.947326	$1.3\cdot10^{-9}$	$8.0\cdot10^{-10}$	6.2E^{-9}	BFGS 20	Identity	Identity
2.	MLP 16-7-1	1.000000	0.999947	0.931071	$9.6\cdot10^{-13}$	$5.8\cdot10^{-9}$	$1.1\cdot10^{-8}$	BFGS 88	Logistic	Identity
3.	MLP 16-5-1	0.999962	0.999980	0.989964	$1.6\cdot10^{-10}$	$3.1\cdot10^{-9}$	$1.4\cdot10^{-9}$	BFGS 45	Sine	Identity
4.	MLP 16-13-1	0.999817	0.999525	0.920695	$7.8\cdot10^{-10}$	$2.5\cdot10^{-8}$	$3.0\cdot10^{-8}$	BFGS 58	Tanh	Exponential
5.	MLP 16-13-1	0.999993	0.999902	0.989725	$3.9\cdot10^{-11}$	$1.2\cdot10^{-9}$	$9.5\cdot10^{-10}$	BFGS 63	Sine	Identity
6.	MLP 16-12-1	0.999985	0.999866	0.989143	$6.7\cdot10^{-11}$	$2.5\cdot10^{-9}$	$1.3\cdot10^{-9}$	BFGS 39	Sine	Identity
7.	MLP 16-12-1	0.999972	0.999781	0.988308	$1.2\cdot10^{-10}$	$3.1\cdot10^{-9}$	$1.7\cdot10^{-9}$	BFGS 31	Sine	Identity
8.	MLP 16-12-1	0.999988	0.999976	0.982417	$5.2\cdot10^{-11}$	$5.5\cdot10^{-10}$	$1.5\cdot10^{-9}$	BFGS 46	Sine	Identity
9.	MLP 16-12-1	0.999995	0.999134	0.997716	$2.3\cdot10^{-11}$	$6.9\cdot10^{-9}$	$7.9\cdot10^{-10}$	BFGS 90	Sine	Identity
10.	**MLP 16-12-1**	**0.999975**	**0.999989**	**0.987183**	$\mathbf{1.1\cdot10^{-10}}$	$\mathbf{3.7\cdot10^{-10}}$	$\mathbf{1.3\cdot10^{-9}}$	**BFGS 40**	**Sine**	**Identity**
11.	RBF 16-12-1	0.956332	0.981168	0.999954	$1.6\cdot10^{-7}$	$2.9\cdot10^{-7}$	$6.0\cdot10^{-8}$	RBFT	Gaussian	Identity
12.	RBF 16-12-1	0.959378	0.905521	0.208775	$1.7\cdot10^{-7}$	$6.7\cdot10^{-7}$	$3.9\cdot10^{-8}$	RBFT	Gaussian	Identity

As seen in Table 2, the analysis of the 12 obtained neural networks resulted in choosing network No.10 MLP 16-12-1 as the best one, which has the highest efficiency in the control sample - control efficiency. It should be further noted that in our case, neural networks of the multilayer perceptron (MLP) type showed better efficiency compared to the radial basis function (RBF).

It is important to emphasize that the sensitivity analysis of the network was conducted, which shows how strongly biomechanical characteristics and anthropometric data affect the sports result in race walking in this case. Thus, in the chosen model the characteristics of stride length and frequency, as well as take-off power and body mass had the highest sensitivity indices, which also confirm the correctness of the chosen model.

Based on the neural network No. 10 MLP 16-12-1 multifunctional biomechanical models of technical actions in race walking in men and women at the stages of preliminary basic (13-15 years old; 3 km distance), specialized basic preparation (16-19 years old; 10 km distance), and in highly skilled athletes, beginning from the stage of preparation for higher achievements and ending with the stage of high sports mastery preservation (20 years old and more; 20 km distance) were created.

Figure 1 shows multifunctional biomechanical models of technical actions in race walking at a distance of 20 km in men, which, during the process of technical training design, create benchmarks for achieving the level of sports results from a high national and world level to those that exceed the world record.

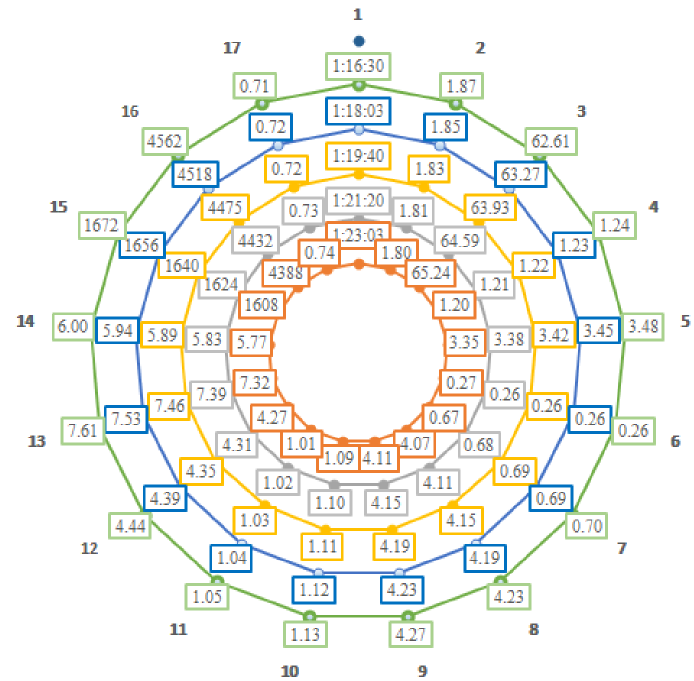

Figure 1. Multifunctional biomechanical models of technical actions in race walking at 20 km distance:

1- Result;
2- Body length, m;
3- Body mass, kg;
4- Stride length, m;
5- Stride frequency, stride•s–1;
6- Single support time, s;
7- Ka – the ratio of stride length to body length, conv. un.;
8- The speed of movement of the BGCM at the moment of foot placing on the support, m•s–1;
9- The speed of movement of the BGCM at the moment of foot detachment from the support, m•s–1;
10- Amplitude of the shoulder joint movement (of ipsilateral limb) in the phase of single support, m;
11- Amplitude of the hip joint movement of the swinging leg in the phase of single support, m;
12- Angular velocity of the hip joint of the swinging leg flexion in the phase of single support, rad•s–1;
13- Angular velocity of the knee joint of the swinging leg extension in the phase of a single support, rad•s–1;
14- Angular velocity of a shoulder joint (of ipsilateral limb) flexion in a phase of a single support, rad•s–1;
15- Resultant force of support reaction in the phase of a single support, H;
16- Take-off power in the phase of single support, W;
17- Ke – the ratio of power to stride length per kilogram of body mass, conv.un

Figure 2 illustrates the models of race walking technique at a 10 km distance for boys (16-19 years old) at the stage of specialized basic preparation, which during the process of technical training design create benchmarks for achieving a high national and world level.

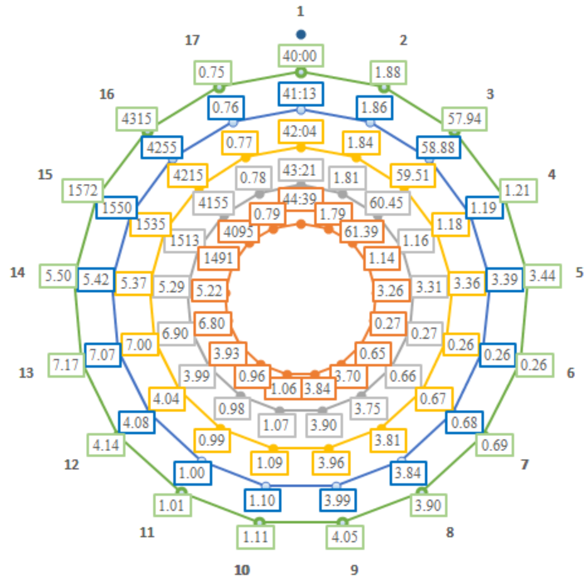

Figure 2. Multifunctional biomechanical models of technical actions in race walking at 10 km distance:

1- Result
2- Body length, m
3- Body mass, kg;
4- Stride length, m;
5- Stride frequency, stride•s–1;
6- Single support time, s;
7- Ka – the ratio of stride length to body length, conv. un.;
8- The speed of movement of the BGCM at the moment of foot placing on the support, m•s–1;
9- The speed of movement of the BGCM at the moment of foot detachment from the support, m•s–1;
10- Amplitude of the shoulder joint movement (of ipsilateral limb) in the phase of single support, m;
11- Amplitude of the hip joint movement of the swinging leg in the phase of single support, m;
12- Angular velocity of the hip joint of the swinging leg flexion in the phase of single support, rad•s–1;
13- Angular velocity of the knee joint of the swinging leg extension in the phase of a single support, rad•s–1;
14- Angular velocity of a shoulder joint (of ipsilateral limb) flexion in a phase of a single support, rad•s–11;
15- Resultant force of support reaction in the phase of a single support, H;
16- Take-off power in the phase of single support, W;
17- Ke – the ratio of power to stride length per kilogram of body mass, conv.un.

Figure 3 depicts multifunctional biomechanical models of the race walking technique at a 3 km distance for boys (13-15 years old) at the stage of preliminary basic preparation, which during the process of technical training design create benchmarks for achieving a high national and world level.

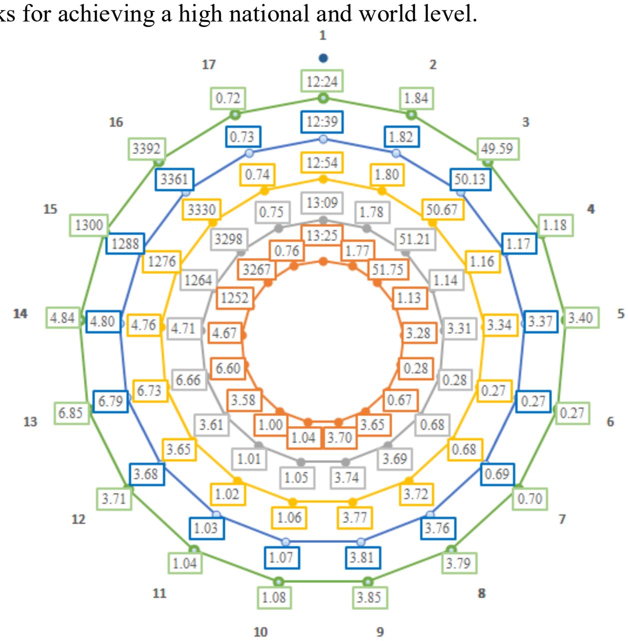

Figure 3. Multifunctional biomechanical models of technical actions in race walking at 3 km distance:

1- Result
2- Body length, m;
3- Body mass, kg;
4- Stride length, m;
5- Stride frequency, stride•s–1;
6- Single support time, s;
7- Ка – the ratio of stride length to body length, conv. un;
8- The speed of movement of the BGCM at the moment of foot placing on the support, m•s–1;
9- The speed of movement of the BGCM at the moment of foot detachment from the support, m•s–1;
10- Amplitude of the shoulder joint movement (of ipsilateral limb) in the phase of single support, m;
11- Amplitude of the hip joint movement of the swinging leg in the phase of single support, m;
12- Angular velocity of the hip joint of the swinging leg flexion in the phase of single support, rad•s–1;
13- Angular velocity of the knee joint of the swinging leg extension in the phase of a single support, rad•s–1;
14- Angular velocity of a shoulder joint (of ipsilateral limb) flexion in a phase of a single support, rad•s–1;
15- Resultant force of support reaction in the phase of a single support, H;
16- Take-off power in the phase of single support, W;
17- Ке – the ratio of power to stride length per kilogram of body mass, conv.un

It should be noted that this article presents only generalized models. However, the developed model enables to model and predict the level of sports result depending on the individual peculiarities of athletes. Thus, by changing one or more indices, it is possible to model or predict the level of result.

On the other hand, important aspects of an individual approach realization in the developed algorithm are not only modeling and forecasting, but also assessing the efficiency and economy of the technique of a competitive exercise performance. For instance, by modeling the data of biomechanical characteristics of each particular athlete technique obtained during the competition, one may compare the level of the achieved sports result with the modeled one. Such an approach allows for determining the correspondence of physical fitness level to that of the athlete's technical skills.

Trends in the development of sports and track and field in particular, indicate an increase in the body length of athletes who achieve the highest sports results (Bobrovnyk & Sovenko, 2024). Therefore, an important aspect of the developed multifunctional biomechanical models is their accounting for anthropometric indices of athletes, namely body length and mass. After all, they took into account the possibility of achieving a certain level of results of athletes who differ significantly in height from the average, or to predict a change in results due to a decrease in body mass. The possibility of applying this approach is especially important in the first stage of long-term preparation, where changes in body length and mass are pronounced during puberty.

Discussion

The main theoretical and ideological component of our studies was that technical training in race walking should be considered as a holistic system in terms of long-term preparation and be based on modern data and benchmarks of the technique of competitive exercise performance (Platonov, 2015).

At the present stage of sports development, improving the level of athlete training, especially technical training, requires the introduction of the latest technologies. Using the relevant technologies, leading scientists K. Hoga-Miura et al. (2006; 2022), B. Hanley et al. (2008; 2014; 2019; 2020), J. Broďani et al. (2011), G. Pavei et al. (2014, 2019) and others analyzed the race walking technique of top-level and national level athletes at the key stages of long-term development. However, they failed to further research the aspect of modeling of technical actions.

Meanwhile, models of athletes' technical actions are an integral part of the practical process of designing and managing technical preparation (Shynkaruk & Serebriakov, 2021; Imas et al., 2018).

Today, neural networks are among the most advanced modeling technologies used in sports. Our research has confirmed the data (Wang, 2021; Zhao et al., 2023) that they provide accurate results and do not require significant physical effort in operation. J. Wang (2021) describing problems in existing traditional methods of predicting athletic performance (such as subject-based assessment based on the experience of coaches, quantitative method of regression analysis with linear dependence, combinations of these qualitative and quantitative assessment methods), argues that the key point for the future development of modeling and predicting sports results is the choice of a predicting method using neural networks that are characterized by a small error, do not require significant physical costs, are characterized by low technical requirements and are suitable for the field of sports.

Our research allowed us to create a model of technical actions of athletes specializing in race walking, in a system of long-term development on the basis of neural networks, which takes into account the informative anthropometric and biomechanical characteristics of the technique of athletes that affect the achievement of high sports results.

Our research has also indicated the significant role of the researcher while using neural networks. This is due to the neural network's ability to learn, find complex dependencies between input and output data, and make generalizations. Therefore, an important point is the quality of the data that the researcher puts into the neural network and the theoretical basis of this or that process or phenomenon that is being modeled or predicted. Thus, the combination of the researcher's knowledge, experience, and creativity and the capabilities of neural networks bring the process of modeling in sports to a new and better level.

The novel models developed by us with the use of neural networks provide guidelines in designing the process of technical training of athletes in the system of long-term development, namely at a distance of 3 km at the stage of preliminary basic preparation (13-15 years old), at a distance of 10 km at the stage of specialized basic preparation (16-19 years old), and at a distance of 20 km in highly skilled athletes from the stage of preparation for higher achievements to the stage of high sports mastery preservation (20 years and more).

It is important to note that the basic model of technical actions of race walkers developed by us has many functions and allows the creation of generalized, group, and individual models at different stages of long-term improvement.

Conclusions

The enhancement of technical training for athletes specializing in race walking within a long-term development system should be grounded in clear criteria that enable the modeling of athletes' technical movements using neural networks. The research allowed us to create a modeling algorithm based on the neural network model, which allows to create generalized, group and individual multifunctional models of technical actions of athletes who specialize in walking in the system of long-term training depending on gender, stage of long-term training of strengths and weaknesses of preparedness.

By employing artificial neural networks, models of race-walking techniques have been developed to support the attainment of high-performance results at various stages of athletic development:

- 3 km distances during the preliminary basic training stage (ages 13–15),
- 10 km distances at the specialized basic training stage (ages 16–19), and
- 20 km distances for highly skilled athletes at the stages of preparation for peak performance and the maintenance of high-level mastery (ages 20 and older).

Future research are needed to employ models based on artificial neural networks to the practice of preparation of athletes of different age categories and specializing in different distances. These findings form the foundation for creating a practical methodology for technical training in the long-term development of race walkers. This methodology represents the focus of our ongoing research efforts.

Conflict of interest

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

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