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MODELING THE COMPETITIVE PROCESS IN ROCK CLIMBING

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The working hypothesis of research was that the effectiveness of the performance of a climber on a route is determined by the indicators of the most important climbing characteristics and is subject to the inner structural laws of the competitive process (CP). In accordance with the hypothesis, researches dedicated to the studies of the system of the CP in the discipline of lead climbing among women have been conducted. For seven years, the starts of highly qualified female athletes on the semi-final and final routes of the World Cup and the World Championships have been studied. The collected indicators made it possible to form the structure of the CP system, which includes 12 components that determine the performance result. Five of them, in accordance with the selection criteria became the core of the system. A neural network was constructed that allows to obtain the correct results using only 3 input variables. Using the variables included in the core of the system, two regression models were constructed for short and long competitive routes 8a+/8b+ categories of difficulty.

Keywords: *rock climbing, competition, efficiency, potential, modeling.*

Introduction

An analysis of the competitive practice of highly qualified climbers allows to state that the performance is determined not only by pre-competition preparation and a number of other factors of competitive activity, but also by understanding the patterns of lead climbing and the ability to use them to demonstrate the highest indicators. For these reasons, the studies of biomechanical and specialized characteristics of climbing that have not been considered before can be a prospective area of research.

Currently, experts in their scientific works more often consider the impact on climbing performance for physiological, anthropometric, somatic and motor characteristics [8]. Research in the field of anthropometry is quite common and very controversial. Thus, the results of the work of Mermier and his colleagues did not confirm the opinion that a climber must necessarily have certain anthropometric characteristics in order to achieve high results [6]. It was also suggested that the determinants of climbing characteristics may be attirbuted more to trainable variables, rather than specific anthropometric characteristics [11].

The results of the search for factors contributing to successful or unsuccessful climbing were published by Draper and his colleagues. One of these factors, according to the authors, is the aspect of reducing the time of active operations at key points of the route [2]. Predicting the effectiveness of climbing through training characteristics: indicators of body composition, muscle strength and endurance, was considered in the work [1]. Researchers modeled the process using structural equations.

An extensive study on the structure of the motor actions of a rock climber was conducted in 2013 [5]. Forty three components were analyzed, of which the seven most important were identified. In other works, specialists have shown that for the perceptual and motor adaptations improving the co-ordination of a climber [7], as well as the climbing indicators that take into account the trajectory of the ascent and the time of the trajectory [10] are very important for improving the effectiveness of climbing.

There are fewer works describing the mechanical parameters of climbing, that, according to authors, are a useful tool for a quantitative assessment of the characteristics of a climber at a particular section of a route [3]. In this area, the kinematics and kinetics of motor actions are studied, taking into account the energy of the movements [9]. The authors have developed a dynamic model for predicting the metabolic aspects of climbing, minimizing muscle fatigue.

This whole range of numerous characteristics, as well as minor (specific) climbing components, determines the success of a performance and has a decisive influence on the result. The structure of this influence is subject to certain rules; if these are not complied with it will negatively impact the effectiveness of climbing and does not contribute to solving the main task of an athlete: maximum realization of competitive potential. However, at present there is no single metric system of physical potential indicators in general and in climbing in particular. Therefore, the question of qualimetry of the climber's potential is one of the important issues to be addressed.

Effective realization of potential is a difficult task and very often neither an athlete nor a coach can solve it. Why does this happen? And what actions by an athlete on a competitive route may contribute to a more successful performance?

In order to find answers to the questions posed, research devoted to the study of the competitive process system (SCP) in the discipline of lead climbing was conducted. Under the competitive process (CP) is considered to be a process of going on the route: from the moment of start to either fall or finish.

The concept of the research included the search for and analysis of biomechanical and specific climbing characteristics of climbing (components of the SCP), interpreting the state of activity of a climber on the route, containing information about their potential and having a direct impact on the final performance result (*Y*). It was meant to simulate the SCP with a minimum number of characteristics that will to obtain a quantitative assessment of the complex actions of the climber at the time of completing the route.

The purpose of the research: the search for the leading components of climbing, the study of the laws of the competitive process that contribute to maximizing the realization of potential and building a model of the SCP in the discipline of lead climbing among women.

Material and methods

All the data presented in the article are based on the analysis of the performances of athletes at major international competitions.

The studies included 3 stages and were conducted over 8 years. At the first stage (2011 — 2012), the concept of research was formulated and the influencing components of the SCP were defined. At the second stage (2012 — 2017), the performances of highly qualified female athletes at the World Cup and World Championships were studied. Video files of the starts were processed in VLC 3.0.4 and Kinovea 0.8.24 and analyzed in the mathematical software Statistika 10. At the third stage (2018), the models built as a result of research were tested at World Cup stages ($n = 7$) and the World Championships in Innsbruck .

A total of 1670 starts at 114 semi-final and final routes of the World Cup competitions ($n = 54$) and World Championships ($n = 4$) were collected and processed. During the processing of each start, the individual indicators of the athlete were simultaneously taken from 8 biometric characteristics, 7 specific climbing components and 2 route parameters. More than 21,200 indicators are included in the generated database, which made it possible to obtain reliable research results.

Results

In contrast to most of the scientific works in sports climbing, the basis of this research were not the issues of pre-start preparation and the training process, but the actions of a female athlete at the time of finishing a competitive route.

The working research hypothesis was that the effectiveness of a climber on a route is determined by the closeness of their indicators to the optimal values for the most important components of the SCP: the closer the indicator, the higher the degree of potential realization.

The analysis of the starts showed that in a situation where the level of readiness of the strongest climbers considering the key positions is virtually equal, and maximum performance is achieved with maximum effort, the degree of influence on the result of less significant, secondary factors is often decisive. And this fact must also be taken into consideration. Taking into account the data of the preliminary analysis, at the first stage of research the determining characteristics of the CP were established:

1. Effective movement (d) — one movement of a climber with fixation of a subsequent hold on a route having a point grade. This component includes all the parts of the pre-start preparation and largely determines the potential of an athlete.
2. Skipped movement (z) — a movement without which the athlete was able to pass the stretch of the route and skip the working hold, while other athletes used this hold. This parameter is a significant indicator of mastery, and is particularly pronounced at the stage of qualifying starts.
3. Recovery time (t_1) — rest pauses used by an athlete during climbing on a competitive route.
4. Pure climbing time (t_2) — the time of active movements.
5. The pace of movement (w). Shows the average time spent by an athlete to perform one effective movement.
6. Density of climbing (ρ). It characterizes the degree of continuity and intensity of the climbing process.

In the course of the research, other variable characteristics were also studied: completion time of a starting segment (d_8), climbing intensity (v), using dynamic movements (q), total climbing time (t), belay factor (s) and incomplete movement (ω). In total, 12 components of the SCP were analyzed [4].

One of the objectives of the research involved the obtaining of a mathematical model to calculate the competitive potential of an athlete for a particular route. It was assumed that such a model should be limited to a small number of variables, allowing the achieving of the required accuracy of the calculation. In this regard, it became necessary to select components that have the most significant impact on the result and that are included in the core of the SCP model.

The parameters of total and partial correlation ($r \geq 0.20$), the significance value of the relation, value of the contribution to the result ($\beta \geq 0.03$) were used for selection criteria. Knowledge of the relation of each component with the result, the type of dependence and the magnitude of the selection criteria made it possible to identify the most important components, form the structure and build a general model of SCPs in lead climbing, figure 1.

The core of the system includes the most important components with a constant influence and possessing the most stable relations with the result. Behind the core are the components of the variable degree of influence, that were put behind the core due to non-compliance with one of the stated selection criteria.

Let us consider one of them: completion time of a starting segment of a route (d_8). The starting segment includes the first eight effective movements. It was necessary to understand how the speed of completing the starting segment affects the final result.

The calculations performed showed (n = 338) that, in general, the degree of paired correlation with the result is in the moderate zone: r = –0.37 and is highly significant, p = 2.2E – 11. At the same time, it should be noted that the correlation practically didn't appear on some routes, and on some it reached r = –0.56 and even r = –0.86 (Xiamen final, 2018). However, the established contribution level is low (β = 0.006) and for this reason the d8 component does not appear in the core of the system. At the same time, it is a fully-fledged element of the model, since under certain conditions set by the algorithm for constructing the starting segment, reducing the time spent on the first 8 movements has a significantly positive effect on the result (p = 1.9E – 17). On such routes, the correlation with the result is r = –0.53, and such values can no longer be ignored.

By a similar principle, the location of each component was determined during the formation of the system structure. The core of the system, together with the result, formed 5 characteristics, with a very high coefficient of determination (R^2 > 0.98), with the exception of the skipped movement component (R^2 = 0.63). Another important characteristic, the recovery time, was derived beyond the boundaries of the core in order to reduce the effect of multicollinearity in regression analysis. Linear graphs of paired relationships are shown in figure 2.

Research was hampered by the need to study not only directly paired relationships with the result, but also internal and intercomponent correlations. Analysis of the correlation matrix, that includes 66 component pairs, made it possible to correct the input model data and revealed a number of implicit but interesting dependencies. For example, in the pair 'recovery time — the time of active movements'

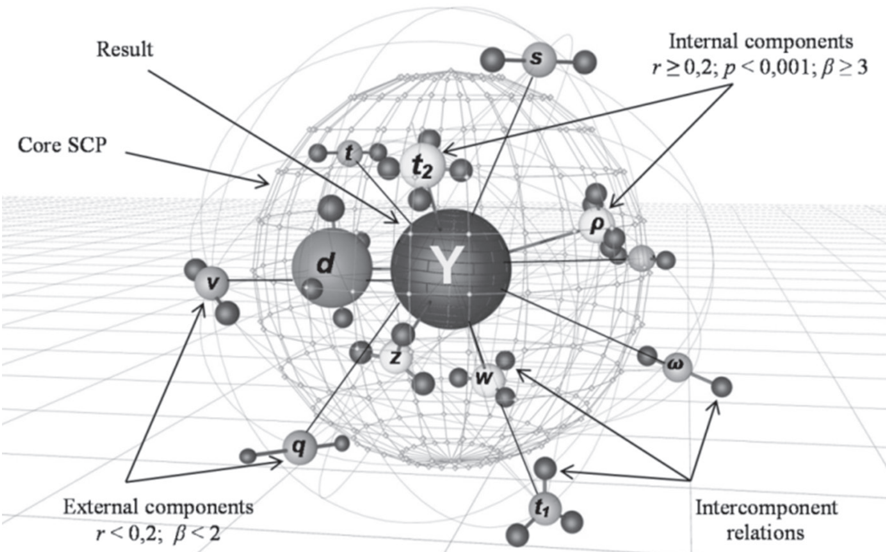

Fig. 1. The system of the competitive process in the discipline of lead climbing

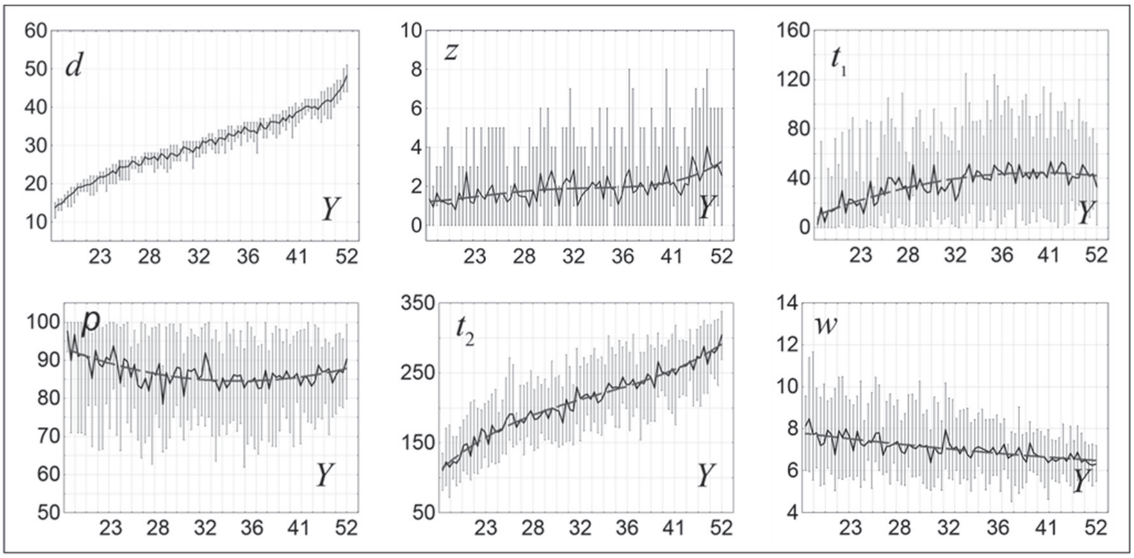

Fig. 2. Matrix diagram of a paired relationship of the components forming the core of the system with the result of the performance

($t_1 - t_2$). The obtained model of a paired correlation showed that the use of rest pauses during climbing the route contributes to the increase in the time of active movements of a female athlete ($n = 1201$; $R = 0.49$; $p << 0.001$). The patterns of such a relation allow to partially predict the growth dynamics of the t_2 component, depending on the duration of recovery pauses. Since this component is the second most important in the SCP and actively contributes to achieving high results ($R = 0.85$; $p << 0.001$; $\beta = 0.08$), the method of managing them during a performance can be very promising and in demand in real competitive practice.

The complexity of the research was largely due to the lack of standardization of routes in the lead climbing discipline. Unlike the speed discipline, where the parameters of the reference route are the same at all competitions, in lead climbing, athletes are offered new routes each time that are different in both length (Y_{top}) and the category of difficulty (K_d). And these are the most important parameters of the route that had to be the reference points. Studies have shown that, depending on these parameters, the values of the climbing characteristics can change, reducing or increasing the degree of correlation with the final result.

The category of difficulty is the main parameter of a climbing route. At major international competitions, the fluctuations of the difficulty category, with rare exceptions, are in the range from 8a+ to 8b+ for women's semi-final and final routes. For the 7 competitive seasons of 2012—2018, out of 114 routes at the World Cups and World Championships, only in 8 cases did the category not fall into the specified interval. We have found that some components are hypersensitive to such fluctuations, but in general, in a given category interval, the considered relations are fairly stable.

Compared to a relatively stable parameter — category, another parameter of the route — its length, turned out to be much more variable. This circumstance dictated the need to divide the competition routes into two groups:

Group 1 — short (s-routes): $Y_{top} \leq 42$;

Group 2 — medium and long (ext-routes): $Y_{top} > 42$.

Of all the routes analyzed, 31 are in the short group. The minimum length is recorded in the semi-finals of the 2012 World Cup stage, Xining (CHN): $Y_{top} = 28$. The maximum value is noted in the final of the 2013 World Cup stage, Mokro (KOR): $Y_{top} = 63$. Such a significant variation in the length of the routes greatly limited the precision of unified model, since the value of the error at the ends of the interval, with $Y_{top} < 32$ and $Y_{top} > 55$, approached the maximum permissible values. For this reason, two SCP regression models were built, each for its own group of routes.

S-model of the first group.

The construction parameters: the ridge regression, the coefficient of the bias of the estimate $\lambda = 0.0006$; input variables 5; the number of starts $N = 413$; the number of observations $n = 2065$; working range of the model $15 \leq Y \leq 42$.

$$Y_s = 1{,}023\sum_{z=1}^{z_i} z + 0{,}918\sum_{d=1}^{d_i} d - 0{,}208w + 0{,}016\rho + 0{,}012t_2 + \varepsilon_i \quad (1)$$

Where Y_s is the theoretical result of performance on a short route; z — the amount of skipped movements; d — the sum of successful movements; w — climbing rate; t_2 is the net climbing time on the route; ρ is the climbing density; ε_i — the effect of unaccounted factors.

Ext-model of the second group.

The construction parameters: the ridge regression, the coefficient of the bias of the estimate $\lambda = 0.0006$; input variables 5; the number of starts $N = 792$; the number of observations $n = 3960$; working range of the model $15 \le Y \le 56$.

$$Y_{ext} = 1{,}008\sum_{z=1}^{z_i} z + 0{,}929\sum_{d=1}^{d_i} d - 0{,}215w + 0{,}015\rho + 0{,}011t_2 + \varepsilon_i \quad (2)$$

Where Y_{ext} is the theoretical result of a performance on a long route.

Regression analysis showed that the value of the input variable contribution partially changes depending on the length of the route. The most stable component is the level of pre-competitive preparation, determined by the number of effective movements. Its value is virtually constant and makes a decisive contribution to the result: for women, $\beta_d = 79\%$ success.

The remaining 21% are divided among the other 4 components in the following proportion (for the ext-model): skipped movements $\beta_z = 7.2\%$; net active actions time $\beta_{t2} = 6.4\%$; rate of movement is $\beta_w = 3.9\%$ climbing density is $\beta_\rho = 3.4\%$. The variations in the contribution of the components are insignificant and do not exceed the value of $\Delta\beta \sim 0.016$.

The main characteristics of the models fully meet the requirements of the regression analysis: $R^2 = 0.9995$; Fisher criterion $F = 162900$ ($p << 0.01$); significance of b-coefficients ($p << 0.01$); Durbin-Watson criterion ($DW_s = 1.73$; $DW_{ext} = 1.83$); residual autocorrelation $r_s = 0.13$; $r_{ext} = 0.08$.

The obtained characteristics provided good precision of the models: the value of the standard error on the training set was $m = 2.3\%$. In the verification process of the control data, the error was even lower.

Discussion

Testing of the models was carried out at the stages of the World Cup and World Championship in the 2018 season. On short routes ($n = 70$), the standard error was $m = 0.51\%$, the maximum error $m = 1.4\%$. On long routes ($n = 150$), the value of the standard error did not change, and at maximum reached 1.6%.

The analysis of errors falling into the zone of kurtosis has shown that they are caused, as a rule, by a sporadic combination of component values. For example, in the case of the maximum error, the French athlete H. Janicot at the semi-final route of the World Championships in Innsbruck, achieved the result $Y = 42$ with a low net time of $t_2 = 186$ seconds, a high climbing rate $w = 4.6$ and a very short rest: $t_1 = 12$ seconds. This rare combination of indicators contributed to the increase in error.

In general, testing on the control data showed good results: in 220 starts on the semi-final and final routes, the maximum error in absolute terms was 0.68 points. Only in 2 starts out of 220 did the theoretical result of the performance differ from the empirical one by 1 point; in the other starts, the results obtained completely coincided with the referee protocols.

Apart from the correlation and regression analysis, the neural network analysis method (multilayer perceptron MLP) was used to search for the most significant components of the CP. Several neural networks of various architectures were built and, experimenting with the number of input variables, we managed to create a network (MLP 3-9-1) that allowed us to obtain the correct results using only 3 input variables, eliminating the variable of pre-competition preparation and the density component of climbing, figure 3.

The network performed on the training set without error ($m = 3.2E - 06$), and showed a low error on the control set. At the same time, the network performance was 5 orders of magnitude higher compared to the regression model. However, from a practical point of view, the neural network turned out to be less efficient, since it only allows the calculation of the absolute potential of the athlete, while the regression model makes it possible to bind to the route of a given length.

Developing mathematical models made it possible to solve the main research tasks: to create a tool for calculating the competitive potential for a specific route and to obtain a quantitative assessment of the effectiveness of the performance.

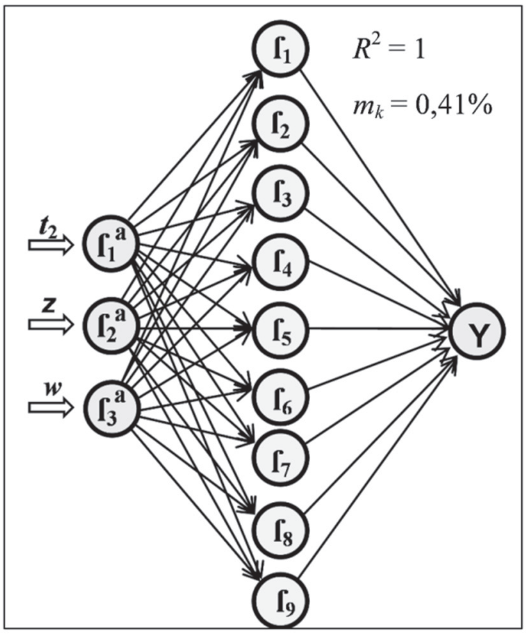

Fig. 3. Neural network architecture

The method of calculating the potential using the proposed model includes a database on the 6 most important components of the SCP, obtained as a result of an analysis of at least 5 starts. These can be official performances or a test on-sight climb on a training route with a category 8a+/8b+. The basic principle of the method is simple: you need to enter the best parameters of a climber in 5 variables into the appropriate model. However, in practice there are serious limitations that do not allow the use of maximum indicators without taking into account the internal intercomponent correlations of the SCP. In addition, it is desirable to know the exact value of the category of the route where this indicator was obtained. The category does not need to be taken into account, but in this case, there is a tangible probability of gross error ($p = 0.07$).

As an example, we will calculate the potential of the Japanese climber Noguchi Akiyo for the final route of the 2018 World Cup in Innsbruck ($Y_{top} = 45$; $K_d = 8b+$). The calculations used data obtained during 10 performances in the 2018 season. Given the intercomponent constraints and the category of the route, the best indicators of the athlete were selected for 5 variables: $d = 34$; $z = 1.83$; $w = 4.76$; $\rho = 98$; $t_2 = 167$.

Entering these data into an ext-model makes it possible to determine the potential of A. Noguchi for the final championship route: $Y_\varphi = 35.7$. That corresponds to an assessment of 35+ in the final protocol.

During the performance, the athlete showed a score of 31 points (Y), while her potential allowed her to receive a score of 35 points (Y_φ). She did not finish, but 35 points gave her the chance to take 3rd place, figure. 4. She remained in 6th place in the final and came 8th in the final protocol of the championship.

The overall performance was 87%. This is a good figure, but not the maximum one. If you conduct a component-based analysis of the start using the ext-model, you can evaluate the performance of the athlete's actions for each component separately and understand the reasons that did not allow her to reach her full potential.

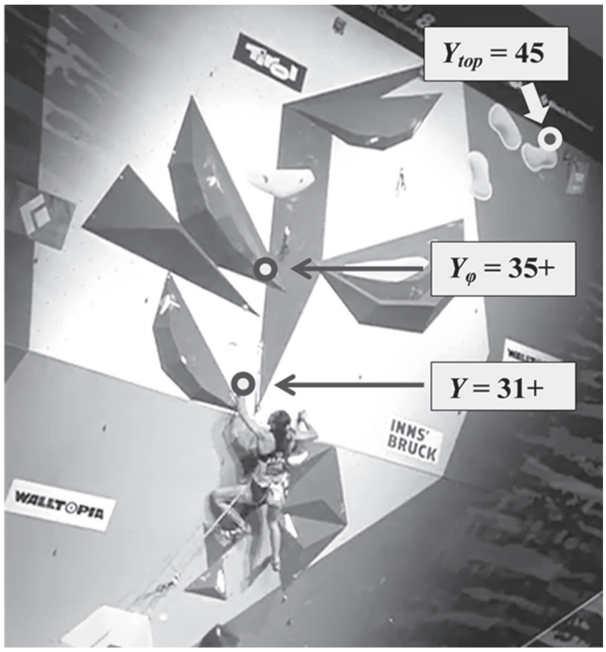

Fig. 4. Relation between the result and potential using the example of the performance of the Japanese athlete A. Noguchi in the finals of the 2018 World Championship

Apart from the advantages indicated, the simulation of the competitive process makes it possible to carry out a multicomponent analysis of a sports performance, determine lost points (cause and number) and see ways to increase competitive efficiency. The implementation of such an analysis is solved by discretization of the judging score using the SCP model.

The model constructed as a result of the research performed is a first generation model and has certain disadvantages. It allows you to accurately calculate the potential and general effectiveness of the performance, but while carrying out a multicomponent analysis it does not take into account one aspect that is essential for climbing. The problem is that in the model under consideration there is no important variable: a technical-tactical error. Athletes often make mistakes, and one serious mistake (or several minor ones) can nullify both a good level of pre-start preparation and the ability to work on the route in the optimal mode. Without taking this component of the CP into account, it is impossible to say which part of the result was lost due to incorrectly chosen climbing modes, and which part was lost due to the erroneous actions of the athlete.

An example is the performance of one of the world leaders in climbing, the Belgian A. Verhoeven in the semi-finals of the World Cup 2018, Villars (SUI). The sportswoman's potential allowed her to fully pass the semi-final route, but already during the twelfth movement, due to the sliding of the leg, she fell. In this case, the analysis of the actions of the athlete using the model will be ineffective, since the overwhelming part of the potential was lost as a result of a gross error.

If the route is passed without errors or the error value is minimal, but the desired result is still not achieved, the simulation allows you to accurately estimate the effectiveness of the climber.

Conclusion

Studying the CP system allows to obtain new knowledge about the patterns of motor actions and tactical and temporal characteristics of climbing the competitive route. Such knowledge opens up broad opportunities in the search for new ways to increase the effectiveness of sports performance and the development of fundamentally new methods for assessing the climbing of the highest category at international competitions. In addition, the simulation allows to evaluate the effectiveness of actions for each component of the CP separately, which makes it possible to teach athletes to use rules of the CP in order to maximize effective climbing. Methods of such training are based on knowledge of the optimum component zone, which can be calculated.

Perspectives

Currently, there are real grounds for improving the system, due to the specification of additional external components that affect the final result and the study of their internal relations. Research in this direction is continuing: an algorithm has been developed for calculating a technical-tactical error and data is being collected. Including this component in the structure of the system will improve the model and find and explore the reserves hidden in the SCP that contribute to the maximum realization of potential.

Practical recommendations

Modeling is a very promising field, allowing the use of theoretical laws in real sports practice. Such knowledge contributes not only to the maximum realization of the climber's abilities at competitions, but also to more effective training in the pre-competition period.

The models developed as a result of research allow:

1. Knowing the practical performance of an athlete on competitive or training routes, you can enter data into the equation, and you can accurately calculate the competitive potential. In this case, the error value will be not more than 2.3% (1 point for the route with a length of $Y_{top} = 44$).

The capacity indicator can be used to predict or decide on the selection of the best trained athletes.

2. Conduct a multicomponent analysis of sports performance, determine lost points (cause and number) and see ways to improve competitive performance.

3. To split the result obtained at competitions into component parts, evaluate the contribution of each of them separately and obtain a general quantitative estimate of the effectiveness of the start.

4. To achieve a higher degree of realization of the potential due to the training of the ability to climb a competitive route in the mode closest to optimal for the most significant components of the CP.

The solution of these and some other problems is possible using a modeling methodology. Such an approach will contribute to the achievement of the maximum result primarily due to the actions of the athlete based on the understanding and optimal control of the laws of the competitive process in lead climbing.

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Моделирование соревновательного процесса в скалолазании

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Рабочая гипотеза исследований предполагала, что эффективность действий скалолаза на трассе определяется показателями наиболее важных характеристик лазания и подчиняется внутриструктурным закономерностям соревновательного процесса (СП). В соответствии с гипотезой были проведены исследования, посвященные изучению системы СП в дисциплине лазания на трудность среди женщин. На протяжении семи лет изучались старты высококвалифицированных спортсменок на полуфинальных и финальных трассах этапов кубка мира и чемпионатах мира. Собранные показатели позволили сформировать структуру системы СП, включающую 12 компонентов определяющих результат выступления. Пять из них, в соответствии с критериями отбора вошли в ядро системы. Построена нейронная сеть позволяющая получить корректные результаты с помощью всего трех входных переменных. С использованием переменных входящих в ядро системы, построены две регрессионные модели для коротких и длинных соревновательных трасс 8a+/8b+ категории трудности.

Ключевые слова: *скалолазание, соревнования, эффективность, потенциал, моделирование.*