VASIL LEVSKI NATIONAL SPORTS ACADEMY

DEPARTMENT "THEORY OF SPORTS"

Dimcho Borisov Mitsov

A MODEL FOR THE CONTROL AND EVALUATION OF TRAINING PROCESS IN LONG DISTANCE RUNNING IN ATHLETICS

ABSTRACT BOOK

for awarding the scientific degree "Doctor"
in a professional direction 7.6. Sports, PhD program
"Theory and Methodology of Sports Science"

Supervisor:

Associate Professor Mihail Konchev, doctor

SOFIA, 2022

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The dissertation contains 212 standard pages. Illustrated with 36 tables, 43 figures and a list of references. The bibliographic reference contains 231 sources, of which 38 in Cyrillic, 190 in Latin and 3 Internet sources.

The numbering of the tables and figures in the abstract matches that of the dissertation.

The dissertation work was discussed and directed for public hearing before a scientific jury at an extended meeting of the "Sports Theory" department at the Vasil Levski National Academy of Sciences, held on 09/29/2022.

The public defense of the dissertation work for awarding the educational and scientific degree "Doctor" will take place on 11.01.2023 at 2:00 p.m. in Hall "A1" of the Vasil Levski National Academy of Sciences, Studentski Grad, Sofia.

Introduction

The main factors related to the management of the training process in long-distance running are the level of training, the level of fatigue and the magnitude of the training load. In view of the correct construction of the training process, it is necessary that each training load be optimal according to the current state of the athlete in the given stage of sports training. The biological factors determining athletic performance in long-distance running are maximal oxygen consumption (VO2max), anaerobic threshold (AnT), muscle energy potential (mainly the level of glycogen in the muscle cell) and running economy (NealA, 2011; Midgley at al., 2007).

Measurement and monitoring of the factors listed above is possible through laboratory and field tests and research, using invasive and non-invasive methods. Some of these methods are expensive and their frequent use is not always compatible with the goals of the training process. Tracking heart rate (HR), as a result of the intensity of the training load, is an easily measurable indicator that is interrelated with the factors related to the management of the training process.

In the current dissertation work, a mathematical model of running efficiency index (RI) evaluating level of training, economy of running, level of fatigue and magnitude of training load was developed. The index is modeled on the basis of a polynomial function V=f(HR) of the second degree or higher and is constructed individually for each athlete, this refines the accuracy in the measurement compared to previous methods. The index includes a methodology for measuring the change in speed depending on the magnitude of the slope during running on uneven terrain. The relationship between the change in speed and the magnitude of the slope is based on the physiological response of the body reported by means of the HR. The proposed model makes it possible to control and evaluate the training load on a daily and complex basis without using additional equipment and without disturbing the integrity of the training process. The index is calculated from the indicators: Heart rate (HR), running speed and terrain gradient measured during physical exertion.

1. Statement of the problem

1.1. Summary of the literature analysis

The effectiveness of the training process depends on the observance of the basic principles of sports training. They are based on biological laws related to the adaptation of the organism to the conditions of the external environment. In the literature review of the current dissertation, basic principles for the implementation of the adaptation processes related to loads characteristic of the training-competition process in long-distance running are considered. In summary, these are: (1) the phases for realizing supercompensation of energetic and structural substances, which increases the potential of certain (stressed) biochemical and physiological functions; (2) the optimal synchronization of the mentioned phases with the components of the training loads (magnitude, nature and direction), which directly correlate with the increase in physical performance and the improvement of running efficiency.

Another problem that is related to the optimization of the training process is the disclosure of the factors of sports achievement. These factors, in turn, can serve to create a normative base of indicators for tracking and controlling the main qualities and functions of the athlete, on which the sports result depends. The key factors in long-distance running are maximal oxygen consumption (VO2max), anaerobic threshold (AnT), muscle energy potential (the level of glycogen in the muscle cell) and running economy (Midgley et al., 2007). The observance of physiological, morphological and sports technical norms in the development of the mentioned indicators are a predictor for the harmonious development of the functions and qualities of the athlete for a specific competitive discipline.

The control and assessment of the phase nature of the training process and indicators related to the factors of sports achievement is a difficult task that requires the use of expensive equipment for measuring physiological and biochemical indicators. At the same time, the mentioned studies are not always synchronized with the tasks of the training process and can lead to its disruption and burden. For this reason, in sports theory and practice, methods are developed to control and evaluate the mentioned factors without violating the integrity of the training process. Such methods have been developed mainly on two principles - tracking the change in HR during training load and sleep and by means of psychological questionnaires for control and evaluation of the level of operative and postoperative fatigue.

In the current dissertation work, we have proposed an index model for staged control and assessment of training, based on the measurement of easily traceable indicators - heart rate (HR), speed and unevenness of the terrain. The developed index is an attempt to upgrade the previously existing indices based on the principle of interdependence between HR and running speed, which is a constant value in a wide range of intensity. The mentioned dependence can be described mathematically and accordingly tracked during loads of different intensity. This allows us to report operatively and postoperatively the change in HR at a relatively constant rate. In practice, the change in the HR of a given athlete over time compared to loads of the same intensity is an indicator of a change in the level of training. From the studied literature, it became clear that such a change is also observed during a load of large magnitude, i.e. the increase in HR while maintaining a constant running speed is an indicator of an increase in the athlete's operational fatigue. On the basis of the mentioned mathematical relationship between HR and running speed, our proposed running efficiency index is able to measure the mentioned changes in the internal environment of the body (measured by means of HR) regardless of the change in external load (running speed). Therefore, the index can be calculated without the need to conduct a standardized test and comply with a condition to maintain a precisely defined speed. Calculated from different combinations of heart rate and speed, its value will be identical and adequately reflect the athlete's condition.

Since the index is affected by the slope of the terrain, the reason for which is that at the same speed against the slope the HR is higher or vice versa on the slope it is lower. The formula with which the index is calculated has the possibility, through the interrelationship between the magnitude of the slope and the change in speed, to adapt the speed when running against or along the slope, to the physiological response of the body measured by the HR. Also, if the ratio between HR and running speed is used to calculate the index, it will falsely show higher economy or fitness if it is calculated before the first or after the second ventilatory threshold. In order to avoid this inaccuracy, the new index will be calculated on the basis of a polynomial relationship between HR and running speed, thereby adequately measuring the change in the linear relationship between the mentioned indicators below the first and above the second ventilatory threshold.

Therefore, an advantage of the index to be validated is increased precision in the measurement, accounting for the change in running speed depending on the slope and the ability to measure and track the level of operative (occurring during training) and postoperative fatigue (recovery between individual training activities) during the training process.

1.2 Working hypothesis

The performed literary analysis and the summary of the scientific results are a prerequisite for formulating the following working hypothesis:

Based on a model reflecting the interrelationships between heart rate, speed and incline, it is possible from any load, regardless of incline and speed, and without the performance of standardized tests, to calculate an index that provides reliable and valid information about running economy and condition of long-distance runners, this is a prerequisite for improving control and improving specific performance in long-distance runners.

2. Purpose, tasks and methodology of the research

2.1. Purpose of the study

To develop a highly informative index of running efficiency, which at the same time is easily applicable in the control of the training process in long runs.

2.2. Tasks of the research

1. To identify and analyze the need to develop a running efficiency index (RI) to control and evaluate training load in long distance running.
2. To bring out the main factors of sports achievement.
3. To develop a mathematical model of running performance index.
4. To develop a model for control and assessment of subjective and objective indicators of fatigue and training load parameters.
5. To validate the derived mathematical model of the index of running efficiency, by comparing its values, measured by data from laboratory tests and training loads carried out by the athletes under study, with the directly measured indicator - speed at the anaerobic threshold level (AnTV).
6. To establish and analyze key indicators related to the functional performance of elite long-distance runners.

2.3. Object of the study

The object of the study is the training process in the long runs of athletics.

2.4. Subject of the study

The subject of the study are the parameters for evaluation and control of the training process in long-distance running.

2.5. Subject of the study

19 highly qualified long-distance runners (N = 19) (16 men and 3 women), mean age ($\overline{X}$) 27.9 years (27.9 ±7.9), body mass index (BMI) 20.5 (20.5 ± 2) were studied. , oxygen consumption 66 ml/min/kg (66.3 ±5), mean rate at AnT level 17.3 (17.3±1.8) (table 10 and appendix 2).

Table 10. Morphological and functional indicators of the examined persons

Name	Age	Height *(sm)*	Weight *(kg)*	BMI	FatP *(%)*	VO_{2max} *(ml/min/kg)*	AnT_V *(km/h)*	$AnT_{\%VO2max}$ *(%)*	AnT_{Ecost} *kcal/kg/km*
S. V.	29	179	66,8	20,8	9,4	75	19,2	88,0	1,02
I.T.	22	187	75,8	21,7	7,0	63	16,8	90,5	1,00
D. M.	33	179	66,3	20,7	15,9	69	17,2	84,1	1,01
Y. N.	37	172	62,1	21	9,3	75	19,2	88,0	1,03
M.S.	25	184	65,4	19,3	6,9	67	19,2	92,5	0,97
A. V.	33	178	61,2	19,3	9,6	66	18,0	87,9	0,97
K.K.	27	182	82,0	24,8	11,2	65	18,0	90,8	0,98
N.P.	28	180	72,2	22,3	7,2	70	16,8	84,3	1,04
А.П.	23	169	62,9	22	19,3	64	15,6	89,1	1,10
M.M.	36	177	73,2	23,4	14,6	58	15,6	93,1	1,04
D.M.	32	179	65,2	20,3	14,2	73	18,0	84,9	1,05
R.L.	46	172	59,2	20	9,2	71	18,0	88,7	1,05
R.N.	14	160	47,3	18,5	13,5	62	14,4	83,9	1,10
K.P.	14	167	41,8	15	10,0	60	13,2	90,0	1,20
M. G.	27	168	60,5	21,4	12,8	59	14,6	91,5	1,11
M.T.	27	182	67,2	20,3	6,1	70	19,6	85,7	0,91
I.A.	19	193	72,3	19,4	5,3	61	17,5	93,4	0,98
M.S.	25	184	67,1	19,8	7,7	67	19,0	91,0	0,97
A.V.	33	178	61,6	19,4	7,7	64	17,5	87,5	0,97
$\overline{X}$	27,9	177,4	64,7	20,5	10,4	66,3	17,2	88,7	1,00
SD	7,9	7,8	9,2	2,0	3,8	5,2	1,8	3,1	0,1

FFM (kg)= Active Body Mass;
MM (%)= skeletal muscle mass;
BMI= body mass index;
BF (%) - body fat content;
EcostAnT - energy cost when running at AnT level speed
$\bar{X}$- mean value;
SD - standard deviation.

2.6. Testing methodology

The study participants underwent two laboratory and two field studies.

The first laboratory test is a submaximal test in which one runs on an incline of different magnitudes. During the test, HR, running speed and oxygen consumption are recorded, and then a running efficiency index is calculated for each of the steps with different gradients. The purpose of the test is to compare the change in the body's physiological response during running against a slope of different magnitudes and on terrain without a slope.

The second laboratory test is a maximum step test to failure. During the test, heart rate, running speed and oxygen consumption are recorded, and then the running performance index is calculated for each leg of the test, which are different in intensity. The purpose of the test is to establish the functional fitness of the subjects and to compare the running efficiency index calculated at each step with the value of the real anaerobic threshold to which the index is equated.

The first field test includes two runs over a distance of 1000m. The first section is run against a slope varying from 7 to 10%, with the Ш corresponding to the 3rd threshold zone. The second section is run along the same slope, but in the opposite direction (downhill), with the NL corresponding to the 2nd threshold zone. During the test, the average HR, elevation gain in meters and running speed during the distance run are measured. The purpose of the test is to determine the change in the body's physiological response, measured by the HR, when running on a flat, uphill and downhill run.

The second field test consisted of four 1,600 m stadium runs of varying intensities, with blood lactate values measured in between. The purpose of the test is to determine exercise zones based on the change in blood lactate value and to model the regression equation of the relationship between the change in heart rate and running speed. Based on the function V=f(HR) obtained from this test, the running efficiency index measured during the training loads carried out by the athletes over a period of one week is calculated.

The training loads carried out by the studied 19 long-distance runners over a period of one week are necessary to validate the index of running efficiency and porous terrain conditions, by comparing its value with the value of the speed index at the anaerobic threshold level. From the conducted training sessions, the average values of HR, average running speed and unevenness of the terrain on which the load was carried out are calculated. The running index is calculated for each training or competition load. The intensity of the training loads that are and at each of which the RI is calculated has the following average percentage distribution by physiological load zones:

– I zone - 45% (upper limit of maximum fat oxidation (FatMax));

– II zone - 31% (upper limit first lactate threshold (lactate = 2 mmol/l) (AeT2));

– III zone - 15% (upper limit AnT);

– IVzone - 7% (upper limit speed upon reaching maximum oxygen consumption (VO2maxV);

– V zone – 3% (above VO_{2maxV}).

The load zones are determined based on the individual threshold zones measured by laboratory and lactate test. The training loads were carried out on terrain with a strong surface texture (asphalt, dirt road, tartan or court stadium) and under relatively stable conditions of the external environment (air humidity, temperature, etc.). Competitors prepare using their own training methodology, which has not been changed for the purposes of this study.

The model was tested using statistical methods for hypothesis testing and regression analysis. Index values calculated from laboratory tests and training loads were compared with directly measured values from ventilatory AnT and lactate AnT (based on a lactate level of 4 mmol/l). The values of RI based on the methodology proposed in this thesis, calculated from data from the laboratory test, were compared with the values of the running index, based on the ratio between HR and running speed ($RI_{HR/V}$).

2.7. Stages of the study

The research was conducted in the period from October 2019 to September 2022. The organization of work on its implementation went through three stages.

First stage: October 2019 – September 2020

Work on building the conceptual framework of the dissertation research and outlining the research strategy and structure of the dissertation work. Selection of the methodological tools of the study.

Second stage: October 2020 – September 2021

Implementation of the basic science experiment. Statistical processing of research results.

Third stage: October 2021 – September 2022. Analysis of the results of the empirical research and formation of the main conclusions. Complete writing of the dissertation and preparation for its internal defense.

2.8. Research methodology

In order to achieve the goal and solve the main tasks, a complex methodology developed on the basis of: (1) a study of literary sources, (2) derivation of the factors of the running efficiency index for control and assessment of training, the level of fatigue and the magnitude of load, (3) mathematical modeling of a running performance index to control and evaluate specific performance in long-distance running, (4) development of laboratory and field tests to validate the model, (5) development of a questionnaire for subjective and objective indicators for fatigue and evaluation of the training load, (6) mathematical-statistical methods for analysis and evaluation of the results obtained from the testing of the examined athletes.

To achieve the research objectives and to solve the previously formulated tasks, a methodology was used, which includes:

1) theoretical methods - to develop the methodological concept and justify the relevance and essence of the researched problem.

- critical analysis.

2) Mathematical modeling methods.

- method of indices.

3) Experimental methods for testing the derived mathematical model for control and evaluation of the training process in long-distance running.

- laboratory testing;

- field testing;

4) The SPSS 25 statistical analysis software package and the following statistical analysis methods were used for the statistical processing of the data.

- variational analysis.

- correlation and regression analysis.

- tests to verify the normal distribution of the data.

- hypothesis testing.

2.9. Modeling of a running performance index to control and evaluate the training process in long-distance running

The resulting equations describing the relationship between the HR and the running speed were obtained on the basis of a test load with a progressive increase in the running speed. They have the following form and graphically represent a polynomial of the third degree or higher:

$$V = aHR^3 + bHR^2 + cHR + d \quad (1)$$

$$HR = aV^3 + bV^2 + cV + d \quad (2)$$

Where

a,b,c and d are parameters of the equation

HR - the change in heart rate

V – the speed corresponding to the heart rate.

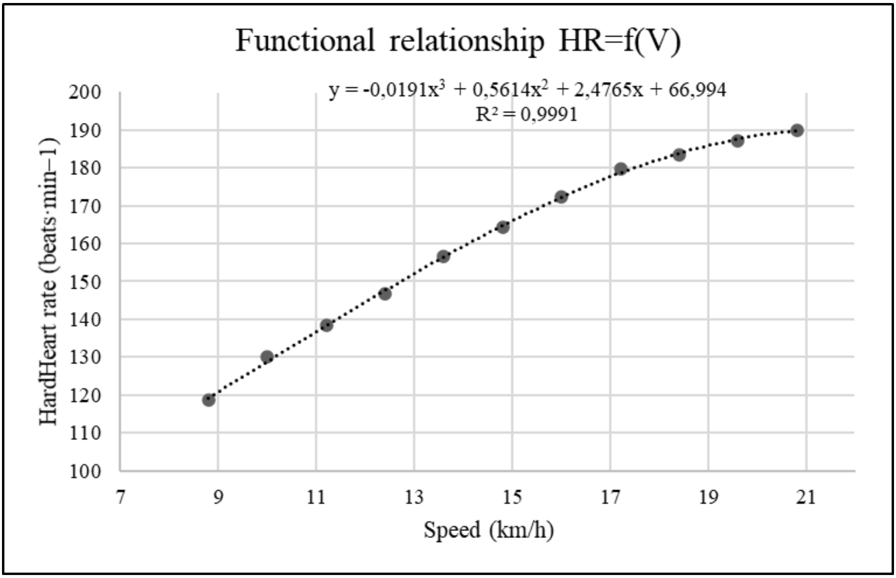

Fig. 29. Functional dependence between HF and speed measured during a step-maximal test to treadmill failure.

If we assume that a given training load is performed after the graph of the function between HR and speed is constructed. Its value, graphically represented as point A, can lie on the curve HR=f(V)(point A) or be to the left or right of it (point A1) (Fig. 30).

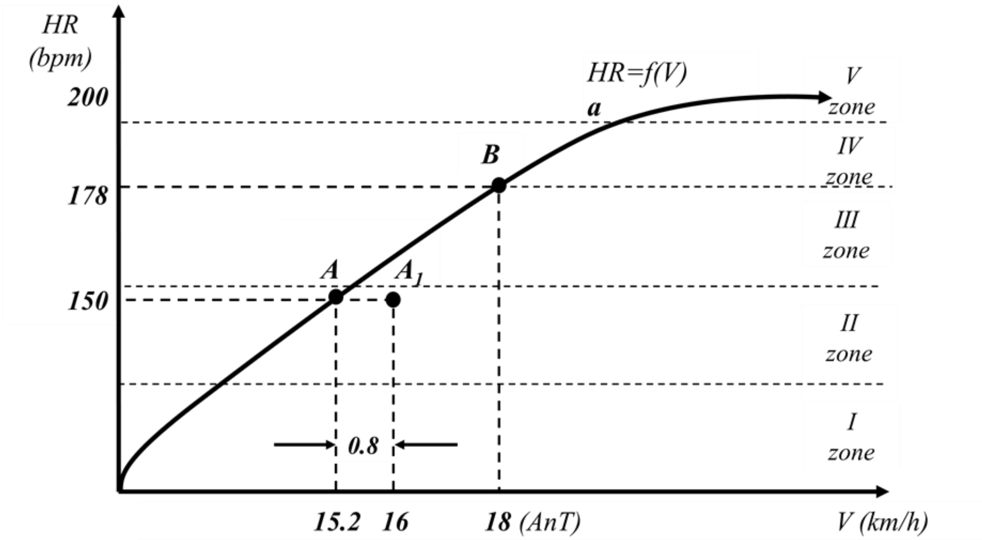

Fig. 30. Graphical model of the modeled running index (RI)

In the event that point A lies on the curve a, as the running speed increases, the athlete's HR will also increase, following the dependence measured by testing. The movement of point A up the curve a will continue until point A coincides with point B, which corresponds to the speed at the AnT level of the given competitor. It can be assumed that the considered position of point A relative to the position of curve a in the short term (within the microcycle) means that no fatigue is observed. In long-term follow-up, if point A remains unchanged, it means that no change has occurred in the athlete's training.

In the event that point A does not lie on the curve a (in the figure - point A1), then the average HR obtained from a specific training load is different from the HR obtained from the conducted testing when running at the same speed. This displacement can have two geometric projections – to the left and to the right of the curve a.

The reason for the displacement of point A from the graph of the function can be due to several factors: a change in the training level of the athlete, a change in the level of fatigue, the surface of the field, the altitude at which the training load is carried out, temperature and humidity of the air, the health condition of the athlete, etc. (Achten, Jeukendrup, 2003; Lambert, at al., 1998; Wilmore, Costill, 1999). If the conditions during the measurement are standardized, the reasons for the displacement of the position of point A will be reduced to two - a change in the training level of the athlete (Buchheit, at al., 2010). and change in fatigue level (Boudet, at al., 2004).

Converting the graphical displacement of item A1 from the graph of the function (curve a) into an empirical value is expedient in order to determine the change in RI as a numerical value.

In the coordinate system, the position of item A1 (obtained from a specific training load) corresponds to a certain HR (150 beats/min) and running speed (16 km/h) (Fig. 30). At the same HR (150 beats/min), curve a (obtained from test load data) intersects at point A, which corresponds to a different running speed (15.2 km/h). This change suggests that the athlete's speed for the particular training load has increased or decreased from that measured in testing. The difference in these speeds can be positive or negative and depends precisely on the position of item A1 relative to curve a. The resulting value is added to the predetermined rate at the AnT level.

Their product represents the RI value. For example, if the speed increases by 0.8 km/h compared to the test data (16 km/h - 15.2 km/h), it is added to the AnT level speed (18 km/h) i.e. 18 km/h + 0.8 km/h=18.8 km/h (fig. 30). The resulting value represents the RI of the specific training load.

Remove the impact of terrain unevenness on RI calculation

A plot of the function between slope magnitude (%) and metabolic energy expenditure during running is relatively linear within ±10% of slope. The loss in velocity during an uphill run is greater than the gain during an identical descent (Minetti, at al., 2002) (Fig. 34).

From the second field test we get the following data:

• HR during uphill running (HR +)(bpm);

• HR during incline running (HR-)(bpm);

• speed while running uphill (V+)(km/h);

• speed during running uphill (V-)(km/h);

• ascent displacement (D+) (m);

• descent displacement (D-) (m);

• uphill distance run (S+) (m);

• downhill distance run (S-) (m).

The slope percentage (D%) is determined by the following formulas:

$$D\%_{+} = \frac{D_{+}}{S_{+}} \tag{3}$$

$$D\%_{+} = \frac{D_{+}}{S_{+}} \tag{4}$$

From the function V=f(HR) (1), the speed of running on undulating terrain, which corresponds to the HR during the ascent (V_{HR+}) and, accordingly, the speed of running on level ground, which corresponds to the HR during the descent, is calculated (V_{HR-}). The speed of running against a slope is lower than that recorded at the same HR on level ground. The speed when running on an incline (descent) is higher than that recorded at the same speed on flat terrain. Therefore, loss of velocity during ascent (Vlost) and gain during descent (Vgane) at constant physiological load (measured by HR) were reported. These two quantities are calculated by formulas (5) and (6) and depend on the D% where the test was conducted.

$$V_{lost}= V_{HR+}-V_{+} \tag{5}$$

$$V_{gane}= V_{HR-}-V_{-} \tag{6}$$

Therefore, there is a relationship between D%, Vlost and Vgane, which is expressed as follows: an increase in D% leads to an increase in Vlost and Vgane. The obtained equations describing the dependence have the following form (Figs. 31 and 32):

$$V_{lost}=a_1D_{\%+} \tag{7}$$

$$V_{gane}=a_2D_{\%-} \tag{8}$$

Where:

a_1 and a_2 are parameters of the linear function

The equation for calculating RI has the following form:

$$\boldsymbol{RI = ((\frac{V_{lost}\ \ Den_{+} - V_{gane}\ Den_{-}}{Den_{+}+Den_{-}} + V) - \ V_{HR}) + V_{AnT}} \tag{10}$$

Where:

RI – running efficiency index, an indirect indicator of the change in speed at the level of anaerobic threshold with included elevation gain (km/h);

V_{lost} - the speed that is lost under the influence of the slope during ascent, according to the following dependence - $V_{lost} = a_1D\%_+$ (km/h);

V_{gane} - the speed that is gained by the influence of the slope during descent ($D_{\%\text{-tren}}$), according to the following dependence - $V_{gain} = a_1D\%$) (km/h);

Den+- the difference in level during ascent (m);

Den- - the difference in level during descent (m);

V - average training speed (km/h);

V_{HR}- the speed of equal, which corresponds to the average heart rate during training (km/h);

V_{AnT} - speed of AnT (km/h).

3. Results and Analysis

3.1. Reliability of the Running Performance Index

Preliminary analysis of the measured values from the tests and training loads showed the presence of a normal distribution, according to the applied Shapiro-Wilk and Kolmogorov-Smirnov tests. This gives us reason to use a one-sample Student's t-test and analysis of variance (ANOVA).

Table 20 presents the results of the individual RI calculated for each stage of the laboratory test to failure and the directly measured anaerobic threshold rate (to which the RI was equated). In order to assess the reliability of our proposed index of running efficiency in the athletes studied, it was compared by means of a one-sample Student's t-test with the speed measured at the anaerobic threshold level by measuring ventilatory parameters and tracking blood lactate during exercise . RI is calculated based on the function V=f(HR) and Vgane/lost=f(D%), constructed from laboratory test data. The obtained results show that there is no significant difference between the investigated indicators at the error level $\alpha = 0.05$ (Sig.>0.005) (table 20). These results indicate that the method by which the running efficiency index is calculated is a reliable method of measuring speed at the level of the anaerobic threshold throughout the range of training-competition speeds. Which means that regardless of the running speed, the index we offer is an indicator of the athlete's training level. The degree of accuracy of the index under standard conditions is a prerequisite for reporting other indicators, such as the level of operative or post-operative fatigue during the training process.

Table 20. Statistical Significance of Mean Difference in RI Measured by Laboratory Test and Anaerobic Threshold Velocity

LABORATORY TEST							
competitor №	***N***	$\overline{X}_{RI}$	$\overline{S}_{RI}$	Mean Difference	AnT_{VE}	Cohen's d	One-Sample T test Sig
1. M.S.	9	18.00	0.24	0.002	18	0.00	.98
2. M.S.	8	18.00	0.16	0.000	18	0.00	.99
3. R.L.	8	16.78	0.18	-0.013	16.8	0.11	.85
4. D.M.	8	17.22	0.15	0.005	17.22	0.00	.93
5. D.M.	11	17.57	0.23	0.018	17.56	0.04	.80
6. S.V.	9	19.19	0.23	0.000	19.2	0.04	.99
7. I.T.	6	16.81	0.16	0.015	16.8	0.06	.82
8. A.V.	8	18.00	0.15	0.001	18	0.00	.99
9. M.M.	7	15.71	0.46	-0.021	15.74	0.07	.91
10. N.P.	9	16.79	0.15	-0.001	16.8	0.06	.98
11. Y.N.	10	19.19	0.28	-0.001	19.2	0.04	.99
12. I.A.	7	18.00	0.15	0.000	18	0.00	.99
13. A.P.	6	15.60	0.09	0.004	15.6	0.00	.92
14. K.K.	7	18.00	0.07	0.000	18	0.00	.99
15. M.T.	10	19.56	0.28	-0.035	19.6	0.14	.70
16. M.Г.	7	14.81	0.06	0.016	14.8	0.17	.50
17. R.N.	8	14.36	0.15	-0.038	14.4	0.26	.50
18. K.P.	6	13.43	0.14	0.003	13.43	0.00	.95
19. A.V.	7	17.47	0.03	-0.025	17.5	1.15	.05
Average values	7,947	17.08	0.18	-0.004	17.09	0.11	.84

N – number of running index studies
$\overline{X}_{RI}$– arithmetic mean value running index
$\overline{S}_{RI}$– standard deviation run index
AnT_{VE}– ventilatory anaerobic threshold

Table 21 presents the results of RI calculated from data from the training loads carried out by the athletes over a period of one week. RI is calculated based on the function V=f(HR) and $V_{gane/lost}$=f(D%) constructed from field test data. RI results obtained from the training sessions were compared with anaerobic threshold velocity values as measured by a blood lactate field test. The indicated indicators were compared using the Student's T-test for one sample. The obtained results show that there is no significant difference between the studied indicators for all studied groups at the error level $\alpha = 0.05$ (Sig.>0.005) (table 21). The purpose of the analysis is to validate the proposed method for measuring the running efficiency index under field conditions, during the real training process carried out by the athletes we studied for a period of one week. The obtained results statistically confirm the reliability of the method also under field conditions.

Table 21. Statistical significance of mean difference in RI measured by data from training loads and velocity at anaerobic threshold level

FIELD TEST							
Competitor №	*N*	$\bar{X}_{RI}$	$\bar{S}_{RI}$	*Mean Difference*	AnT_{LT}	Cohen's d	One-Sample T test Sig
1. M.S.	10	18.01	0.52	-0.191	18.2	0.37	.27
2. M.S.	24	18.61	0.50	0.014	18.6	0.03	.89
3. R.L.	10	17.43	0.60	-0.013	17.56	0.23	.49
4. D.M.	8	17.17	0.25	-0.047	17.22	0.19	.61
5. D.M.	16	17.10	0.41	0.293	17	0.25	.33
6. S.V.	16	19.44	0.41	0.165	19.5	0.14	.01
7. I.T.	12	16.53	0.36	-0.085	16.36	0.46	.14
8. A.V.	11	17.12	0.32	0.370	17.2	0.27	.40
9. M.M.	9	14.89	0.52	-0.140	14.52	0.72	.06
10. N.P.	9	17.42	0.44	-0.162	17.56	0.32	.37
11. Y.N.	14	19.04	0.46	-0.071	19.2	0.36	.21
12. I.A.	24	17.83	0.44	0.036	17.9	0.16	.44
13. A.P.	16	15.44	0.35	-0.214	15.4	0.10	.69
14. K.K.	20	18.19	0.48	-0.199	18.4	0.44	.06
15. M.T.	16	19.31	0.41	-0.013	19.5	0.49	.07
17. R.N.	12	14.99	0.35	-0.085	15	0.04	.89
19. A.V.	11	17.12	0.52	-0.191	17.2	0.16	.40
Average values	14	17.39	0.43	-0.031	17.43	0.28	.37

N – number of running index studies
$\bar{X}_{RI}$ – arithmetic mean value running index
$\bar{S}_{RI}$ – standard deviation run index
AnT_{VE} – ventilatory anaerobic threshold

In order to evaluate the effectiveness of the running performance index proposed by us, its values were compared with the values obtained from the most commonly used method for calculating the running performance index based on the relationship between the HR and running speed. Table 22 presents the results of the running efficiency index calculated by the proposed methodology (RI) and the index calculated by the

HR/V ratio method (RIHR/V). The dispersion of the values around the arithmetic mean, expressed as a percentage, gives information about the precision of the method. When comparing the results of the respective indicators (RI and $RI_{HR/V}$), a coefficient of variation (V%) was used, which gives information about the dispersion of the values around the arithmetic mean value in percentages. The lower the coefficient of variation, the more accurate the method.

The average value of the coefficient of variation (V%) for the running efficiency index is between 0.96% and 1.4% (with an average value of 1%). When testing, using the HR/V method, the variation is within the limits of 3.6 to 4% (with an average value of 3.8%) (table 22). The obtained values show the high degree of precision of the proposed method, compared to the method based on the ratio between HR and running speed (HR/V). It can be seen that the variance calculated by the coefficient of variation of our proposed method is 3.8 times smaller compared to the method of the ratio of HR and running speed, indicating a higher precision of the method.

Table 22. Results of a comparison between the dispersion of RI values calculated by the methodology proposed in the dissertation and RIHR/V calculated based on the ratio between HR and running speed measured during the laboratory step test to failure

COMPARISON TABLE RI/$RI_{HR/V}$							
		RI			*$RI_{HR/V}$*		
competitor№	N	$\bar{X}_{RI}$	$\dot{S}_{RI}$	*V%*	$\bar{X}_{RI}$	$\dot{S}_{RI}$	*V%*
1. M.S.	9	18,00	0,238	1,3	5,19	0,208	4,0
2. M.S.	8	18,00	0,161	0,9	5,24	0,168	3,2
3. R.L.	8	16,78	0,181	1,1	6,29	0,365	5,8
4. D.M.	8	17,22	0,154	0,9	6,24	0,203	3,2
5. D.M.	11	17,57	0,227	1,3	6,72	0,267	4,0
6. S.V.	9	19,20	0,229	1,2	4,83	0,272	5,6
7. I.T.	6	16,81	0,156	0,9	5,84	0,077	1,3
8. A.V.	8	18,00	0,150	0,8	5,16	0,083	1,6
9. M.M.	7	15,71	0,458	1,6	6,42	0,225	3,5
10. N.P.	9	16,79	0,154	0,9	5,39	0,130	2,4
11. Y.N.	10	19,19	0,277	1,4	5,18	0,111	2,1
12. I.A.	7	18,00	0,153	0,8	6,17	0,210	3,4
13. A.P.	6	15,60	0,086	0,6	6,74	0,172	2,5
14. K.K.	7	18,00	0,065	0,4	6,289	0,311	5,0
15. M.T.	10	19,56	0,278	1,4	5,48	0,229	4,2
16. M.Г.	7	14,81	0,058	0,4	6,53	0,371	5,7
17. R.N.	8	14,36	0,153	1,1	8,39	0,549	6,5
18. K.P.	6	13,43	0,136	1,0	8,752	0,558	6,4
19. A.V.	7	17,47	0,026	0,2	4,88	0,091	1,9
Average values	7,947	17,08	0,176	1,0	6,09	0,242	3,8

N – number of running index studies
$\bar{X}_{RI}$ – average arithmetic value running index
$\dot{S}_{RI}$ – standard deviation running index
AnT_{LT} – lactate anaerobic threshold
RI – running index calculated according to the methodology proposed in the present scientific work
$RI_{HR/V}$ – running index based on the relationship between heart rate and running speed

In order to verify the method proposed by us for reporting the physiological response of the body during running against a slope, it is necessary to compare the following indicators: the change in oxygen consumption and the change in HR in laboratory and field conditions. Tables 22 and 24 present the results of Vlost speed loss when overcoming a +1% slope measured based on the change in oxygen consumption depending on the slope magnitude during the first laboratory test ($Vlost_{1\%V2max}$) and the speed loss when overcoming a 1% slope measured on the basis of the change in HR depending on the magnitude of the slope during the first laboratory and field test ($Vlost_{1\%HRlab}$ and $Vlost_{1\%HRter}$).

The obtained results show that there is no significant difference between Vlost $_{1\%V2max}$, Vlost $_{1\%HR}$ and $Vlost_{1\%HR}$ at the error level α = 0.05 (Sig.= 0.735>0.05) (Table 23). This shows that the change in HR is a reliable method for measuring energy expenditure in uphill running, which directly corresponds to our proposed index.

Table 23. Analysis of variance results for the compared groups of values for $Vlost_{1\%V2max}$, Vlost $_{1\%HR}$ and $Vlost_{1\%HRtre}$

ANOVA					
Загуба на скорост при 1% наклон					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,012	2	,006	,310	,735
Within Groups	1,049	54	,019		
Total	1,061	56			

In order to verify the model proposed by us for considering the influence of the slope on the change in speed, it is necessary to compare the following indicators: index of running efficiency measured at different slope of the path in laboratory conditions and speed at the anaerobic threshold level.

Average running performance index values were measured as follows:

First laboratory test - second stage at 3% path slope (RI_{2stage}) and third stage at 6% slope (RI_{3stage});

Second laboratory test - the value of the fan speed AnT (AnT_V), on the basis of which the measured indices of running efficiency were equated.

Table 26 presents the results of the variance analysis of the indicators RI_{2stage}, RI_{3stage} and AnT_V. The obtained results show that there is no significant difference between the compared indicators at the error level $\alpha = 0.05$ (Sig.= 0.922>0.05) (table 26). This is a prerequisite for the claim that the methodology we used is a reliable method for accounting for the change in running speed depending on the incline.

Table 26. Results of the analysis of variance for the compared groups of RI_{2stage}, RI_{3stage} and AnT_V values

ANOVA					
RI_{2stage}, RI_{3stage} u AnTV					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0,578	2	0,289	0,081	0,922
Within Groups	193,103	54	3,576		
Total	193,681	56			

3.2. Study of the relationships between morphological, functional indicators and speed at the level of anaerobic threshold

The purpose of the analysis is to determine the interrelationship between the functional and morphological indicators of the subjects and the speed at the anaerobic threshold level. The data from the analysis can be used to prepare normative tables.

From the performed correlation analysis, it was found that the indicator speed at the level of anaerobic threshold (AnT_V), to which the index of running efficiency proposed in this dissertation is reduced, correlates statistically significantly with the following indicators (fig. 43): relative maximum oxygen consumption - $VO_{2max /kg}$ (r = .755**), absolute maximal oxygen consumption - VO_{2max} (r = .553*), maximal velocity reached during the step function test to failure - V_{max} (r = .842**), velocity at reach at aerobic threshold level - AeT_V (r =.804**), oxygen consumption at aerobic threshold level - AeT_{VO2} (r =.536*), relative energy expenditure for running one kilometer at aerobic threshold level $AeT_{En/cost/km}$ (r =-,737**), oxygen consumption at the level of maximal fat oxidation - $FatMax_{VO2}$ (r =,546*), velocity at the level of maximal fat oxidation - $FatMax_V$ (r =,770**), oxygen consumption at the level of anaerobic threshold - AnT_{VO2} (r =.866**), relative energy expenditure for running one kilometer at anaerobic threshold level - $AnT_{En/cost/km}$ (r =-.690**), speed at respiratory quotient level equal to unity - $RER1_V$ (r =.915**), oxygen consumption at oxygen quotient equal to unit - $RER1_{VO2}$ (r =,659**), body fat percentage - FatP% (r =-,479*), muscle mass percentage - MM% (r =,518*). The observed correlations were between RI and all indicators that indicate performance and economy during running at an intensity characteristic of the main physiological threshold zones (FatMax, AeT, AnT and RER=1). The results of the performed analysis support the statement that the running index takes into account the changes in the level of work ability (training) in the entire spectrum of intensity during exercise.

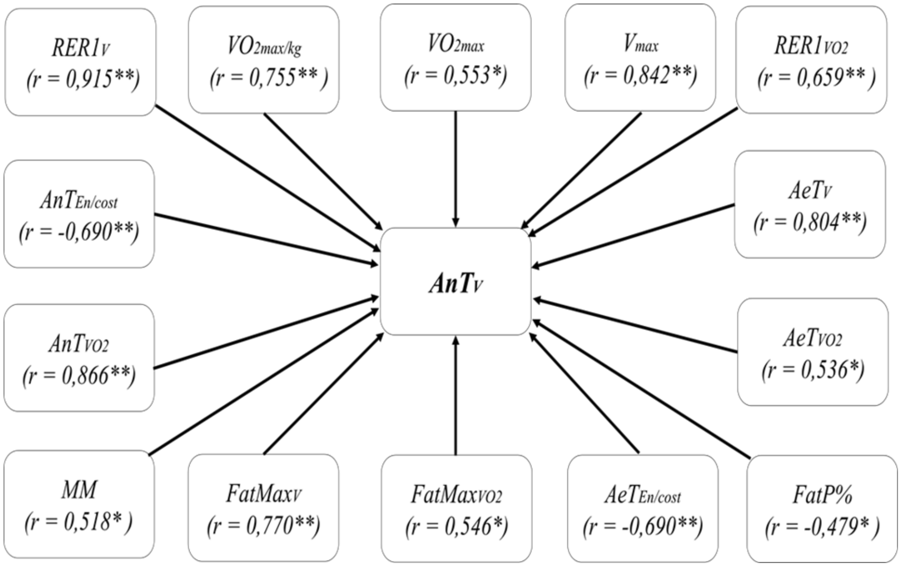

Fig. 43. Statistically significant correlations between functional and morphological indicators and speed at anaerobic threshold level represented by the running efficiency index expressed as speed at anaerobic threshold level

Conclusions and recommendations.

Conclusions

1. The Running Performance Index is a reliable method for determining anaerobic threshold speed. This is confirmed by the absolute (small systematic error, no significant differences) relative (very high intraclass correlation coefficients) reliability statistics.
2. The index also has a high level of validity regarding long-distance running performance. Specifically, it provides the most information about the level of economy and aerobic power indicators.
3. The index has a numerical expression, equated to a specific physiological or racing speed, which facilitates tracking and interpretation of the data obtained.
4. The change in HR is a reliable method for measuring the energy expended when running against an incline with the same physiological response of the body, which directly corresponds to our proposed index.
5. The methodology we used is a reliable method of accounting for the change in running speed depending on the slope for the same functional load. Thanks to the equations derived, describing the dependence between slope, speed, speed and energy consumption, it is possible to calculate an index that adequately takes into account the workability and economy without worsening or improving its value due to changes in speed or slope.
6. The results of the present study show that the presented method for calculating the running index is more precise than the method of the ratio HR/velocity.

7. Tracking the dynamic change of running efficiency index values during running can have a practical application for assessing the level of operative and postoperative fatigue, load magnitude and supercompensation phase reached.

Recommendations

1. Running efficiency index values to be calculated by load zones. This can serve as an indicator of specific training, level of post-operative and operative fatigue in the respective load zones.
2. The application of the index should be under the same training conditions in order to improve its reliability.
3. The level of training to be tracked by means of the index proposed by us for a long period of time.

Scientific contributions

1. The main functional and morphological indicators, having a significant influence on the speed at the level of anaerobic threshold in the studied long-distance runners, are derived - a scientific and applied contribution.
2. A mathematical model of a running efficiency index has been developed for control and assessment of specific performance in long-distance running - a scientific contribution.
3. The developed model was tested on nineteen elite long-distance runners, and its validity was established - contribution attached.

Publications related to the topic of the dissertation:

1. Mitsov, D., (2020). Specifics of energy supply in the long runs of athletics; Athletics & Science no. 1(20), pp. 40-48; ISSN 2603-4263, Sofia.
2. Mitsov, D., (2021). Biological factors of athletic performance in long-distance running in athletics; Athletics & Science no. 1(21), pp. 36-46; ISSN 2603-4263, Sofia.