Original Article

World records in running: The experience of ergometric analysis

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ABSTRACT

Analysis of record achievements in athletics has almost a century of history. The leading method during the study was the ergometric measurement method. Ergometric analysis of the results was performed proceeding from the relationship between the length of the distance and the limit time to overcome it. Analysis of record curves at different running distances was performed on the basis of the technique proposed by N.I. Volkov. To analyse the growth of record achievements, we also applied the logarithmic transformation of exponential dependence. Ergometric analysis of record curves displayed that with each new exponential spike in the improvement of results, an increase in the endurance coefficient is noted. It was established that athletes who train to overcome long running distances have better ergometric indicators characterizing aerobic performance: they are characterized by a higher coefficient of "*critical speed*" and a less pronounced decrease in the curve of the dependence "*speed – time*". And middle-distance athletes were characterized by large values of power factor, which gives clear advantages upon performing intense muscular work. The data obtained by us in the analysis of record achievements in short distances and the forecast of records for these distances allowed to distinguish four stages throughout the history of record achievements in athletics, within each of which occurred a radical reorganization of the training methodology used.

Keywords: Athletics; Muscle activity; Energy-supplying processes; Achievement curve.

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INTRODUCTION

Analysis of record achievements in athletics has almost a century of history. The first attempt to isolate information on the mechanisms underlying muscle activity from achievement curves was made by A. Hill (Hill, 1925). To him also belongs the idea of constructing a graph of the ergometric dependence "*speed – time*", and the author used a clear graphoanalytical method, proposing to depict this dependence on a logarithmic scale, which enabled the judgement on the so-called critical points corresponding to the inclusion of a certain bioenergetic mechanism.

As A. Hill suggested (Hill, 1925), the record achievement curves contain so much valuable information that leading experts in the field of bioenergy took up this line of research, and the first to critically approach this problem was V.S. Farfel. Like A. Hill, he managed to isolate separate segments on the logarithmic curve of records – 4 zones of relative power. The maximum power zone included distances of athletic running 100 m and 200 m, and the submaximal power zone included distances from 400 m to 1,500 m. The high power zone includes distances from 1,500 m to 10,000 m, and the moderate one over 10,000 m. Works of F. Henry (Henry, 1954; Henry, 1955) and R. Margaria (1963) on energy sources for muscular activity confirmed the idea that the physiological meaning of power zones is to change the nature of energy supply. Thus, F. Henry (Henry, 1954; Henry, 1955) presented the "*world record curve*" in the form of a five-membered exponential expression (Equation 1):

$$V = \sum_{i=l}^{S} Ae^{k_i t}, \tag{1}$$

where the first term corresponded to the energy consumption for starting acceleration, the second – to the decomposition of macroergic phosphorus compounds, the third – to glycolysis, the fourth – to aerobic oxidation of carbohydrates, and the fifth – to aerobic oxidation of fats. According to F. Henry, the record curve reflects a decrease in energy supply from corresponding energy sources. The data of A. Hill, F. Henry, V.S. Farfel (Farfel, 1945) were subsequently confirmed and detailed in the works of N.I. Volkova (Volkov, 1962; Volkov, 1964; Volkov, 1968), N.V. Yaruzhniy (Yaruzhniy, 1985), V.E. Borilkevich (Borilkevich, 1989), V.F. Ovchinnikov (Ovchinnikov, 1975), V.D. Sonkin, O.V. Tiunova (Sonkin and Tiunova, 1989), M.R. Smirnov (Smirnov, 1990).

In this work, the ergometric measurement method was applied.

The object of the study was bioenergetic shifts in the body of athletes at different distances of athletic running, and the subject matter was bioenergetic factors that limit the level of sports achievements in running at different distances and determine the efficiency of the applied training means and methods.

The purpose of the study is to study bioenergy factors that determine the level of sports achievements in athletics, to establish the possibility of using bioenergy indicators for the systematization and regulations of training loads in running.

Research objectives

1. To establish the role of bioenergy factors of aerobic and anaerobic metabolism based on ergometric analysis of record curves in running.
2. To study the parameters of power, capacity and efficiency of aerobic and anaerobic performance of highly qualified athletes specializing in various distances of athletic running.

3. To systematize running exercises based on bioenergy criteria.
4. To determine the possibility of using bioenergy criteria in the quantitative assessment and rationing of training and competitive loads in running.
5. To establish the main methodological approaches in optimizing the construction of a training in running using bioenergy criteria.

MATERIALS AND METHODS

To solve the set goals and objectives, 3 groups of methods were used: experimental measurement methods, computational and statistical methods. In accordance with sports qualifications, the subjects were grouped into four groups: world-class athletes; athletes who are part of the national team; athletes of the first category; athletes of the second category.

The first thing the dissertation research was devoted to being the ergometric analysis of record achievements in athletic running. The dependence "*distance – time*", derived from the personal achievements of athletes from the experimental groups, was linear in nature and had a number of noticeable differences between subjects at medium and long distances.

Figure 1 demonstrates a graph of the dependence "*distance – time*", built by world records from 1910 to 1999 for male athletes in running distances of 100 m to 10,000 m. Over a period of time from 1910 to 1999 record achievements improved mainly due to an increase in aerobic performance. Anaerobic performance has changed insignificantly, which expressly displays the existing tendency in big sport – to train the aerobic abilities of athletes.

Indeed, the possibilities of an aerobic energy supplying system are practically unlimited and aerobic training has great prospects in this regard. On the other hand, an increase in the share of aerobic training sometimes closes the path to improving anaerobic bioenergy processes that play the most direct role in ensuring intense muscular activity (Savelev I.A., 2001; Volkov N.I., Savelev I.A., 2002), in that area of physical exertion, where the level of energy consumption significantly exceeds the maximum oxygen consumption and where any increase in the intensity of the exercise is provided exclusively by anaerobic energy sources (Volkov N.I., 1968).

The level of sports achievements depends on how successfully and, from a physiological standpoint, justified it is to use a certain means of training, how effective the directed adaptation of an athlete to physical activity is in the training process. It is quite certain that any changes in the methodology of the used training, associated with changes in the bioenergetic orientation of the exercises applied, will directly affect the rate of improvement of sports achievements.

Analysis of record curves at different running distances was performed on the basis of the technique proposed by N.I. Volkov (1960, 1970). Figure 2 expressly display six periods of improvement in athletic performance. The duration of the noted periods of exponential improvement in record results (t) gradually reduces with each new spike, while reaching a relatively stable level. If we refer to the total value of the increase in the record result within each of the spikes (D t), it gradually decreases within the first three spikes (up to 1954). Subsequently (in the period of the 1950-1960s), the growth of record results increased significantly, and then gradually decreased with each successive spike of a new improvement in record achievements.

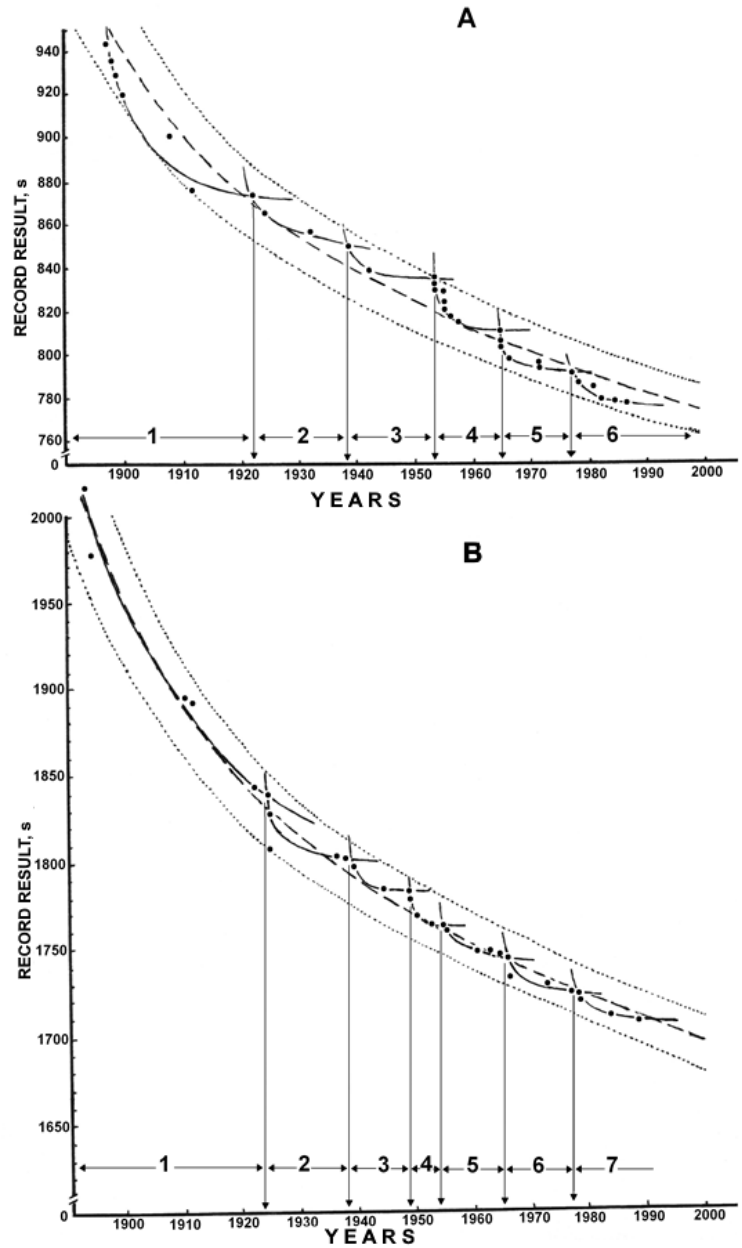


Figure 1. Dependency diagram "*distance – time*".

Improving athletic performance in running at different distances depends on a change in the basic methodological settings in the training of the world's leading runners. Analysis of ergometric dependencies "*speed – time*" and "*distance – time*", made according to world records in running, established from the past decades of the 20th century, show that the improvement of the methodology for training the world's leading runners for medium and long distances until the mid-50s occurred mainly due to the improvement of the aerobic training of athletes. With the implementation of various options of the interval training methods in the training of leading runners, the emphasis on the development of special endurance became even more pronounced because of the increase in the parameters of anaerobic indicators of bioenergy qualities of athletes.

Ergometric analysis of the dependences "*speed – time*" and "*distance – time*" according to world records in running allows us to establish, on a strictly quantitative basis, the role of factors of aerobic and anaerobic energy conversion at separate distances of athletic running. At the athletic running distances associated with the work area of maximum relative power, the contribution of anaerobic energy sources (lactate anaerobic process and anaerobic glycolysis) is from 90 to 95%. In the submaximal relative power range (running distances from 200 m to 1,500 m), the contribution of anaerobic energy sources is 70–40% of the total energy costs. The proportion of energy converted during the aerobic oxidation of carbohydrates varies from 30 to 60% of the total energy demand. At long running distances (in the range of high relative power work), the ratio of the energy production sizes of anaerobic and aerobic metabolic energy sources is 20 and 80%, respectively.

Ergometric analysis of the results was performed on the basis of the relationship between the length of the distance and the limiting time to overcome it (Equation 2):

$$S = a + b \cdot t, \tag{2}$$

where S is the length of the distance (m), t is the time to overcome the distance (s), and a and b are constant coefficients.

Coefficient "*a*" allows to assess the length of the distance that the athlete can overcome solely due to anaerobic energy sources. The value of the coefficient "*a*" corresponds to the length of the segment that is cut off from the zero ordinate of the line drawn along two experimental points. Coefficient "*b*" corresponds to the highest value of speed that the athlete maintains due to aerobic energy sources. The coefficient "*b*" is calculated as the tangent of the angle of the line on the graph.

The functional relationship between travel time and average speed is set by a power equation (Farfel, 1945) (Lv. 3):

$$V = A \cdot t^{-p}, \tag{3}$$

where V is the average speed at a distance (m/s), t is the limiting time of overcoming it (c), A is the power factor representing the value V at t = 0, p is the angular coefficient (endurance indicator) characterizing the speed of the speed drop with increase in distance.

The given functional dependence, when presented on a logarithmic scale, has the form of a straight line that passes through the points corresponding to individual distances and cuts off the segment on the zero axis of the ordinate equal to the power factor "*A*", the absolute value of which is determined by the inverse logarithm. The value of the p coefficient on the graph is calculated as the slope ratio of the line.

RESULTS AND DISCUSSION

Analysis of record curves at different running distances was performed on the basis of the technique proposed by N.I. Volkov (Volkov, 1970; Volkov, 1974). Figure 1 (A) demonstrates the curve of the record growth in running 5,000 m, constructed per the world records at this distance over the period from 1886 to 2000. Figure 1 (A) clearly indicates six periods of improvement in athletic performance. Within each of the identified periods of explosive record growth, the dynamics of record results can be described by the equation (Equation 4):

$$T_{rec.} = T_{in.} \cdot e^{-k \cdot t}, \tag{4}$$

where $T_{rec.}$ is the record result set at a certain point in time t from the start of the modern Olympic Games; $T_{in.}$ is the initial result at the starting point of the exponential curve; k is the constant for improving record results, years; t is the time from the beginning of the 20th century, years; e is the base of the natural logarithms.

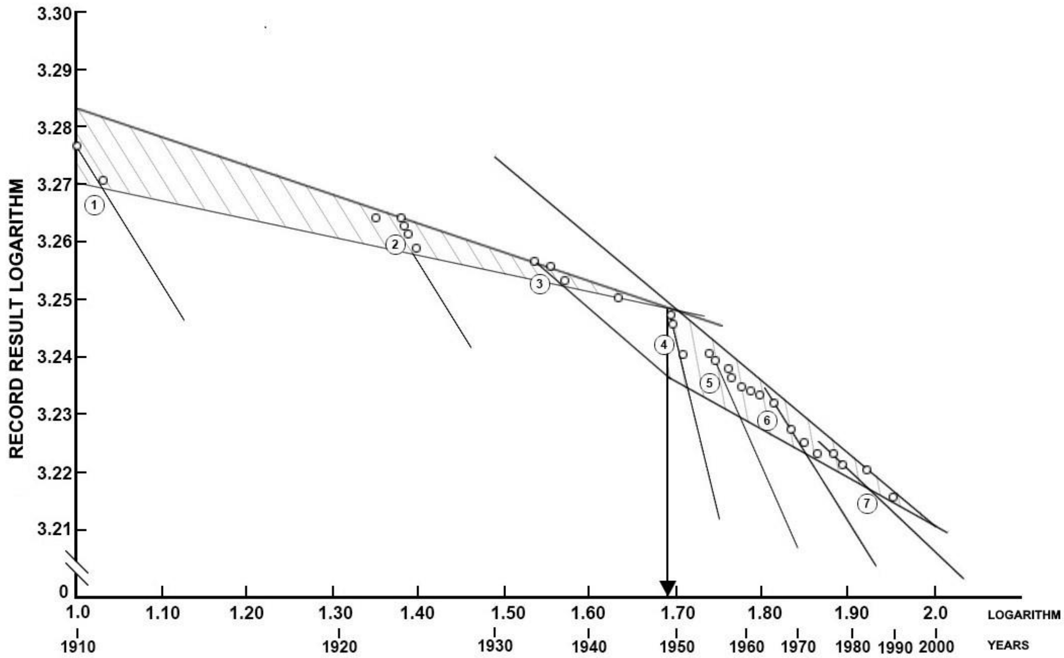
The duration of the noted periods of exponential improvement in record results (τ) is gradually decreasing with each new spike, reaching a relatively stable level over the last 13 years marked on the graph. If we refer to the total value of the increase in the record result within each of the spikes (Δ , it gradually decreases within the first three spikes (until 1954). Subsequently (in the period of the 1950-1960s) the growth of record results increased significantly, and then gradually decreased with each successive spike of a new improvement in record achievements.

The curve of record achievements in running at 10,000 m (Figure 1. B). As is evident, this curve is surprisingly similar to the curve built for a distance of 5,000 m, but on it we can find another, additional spike in the improvement of record achievements, which occurred in the early 1950s.

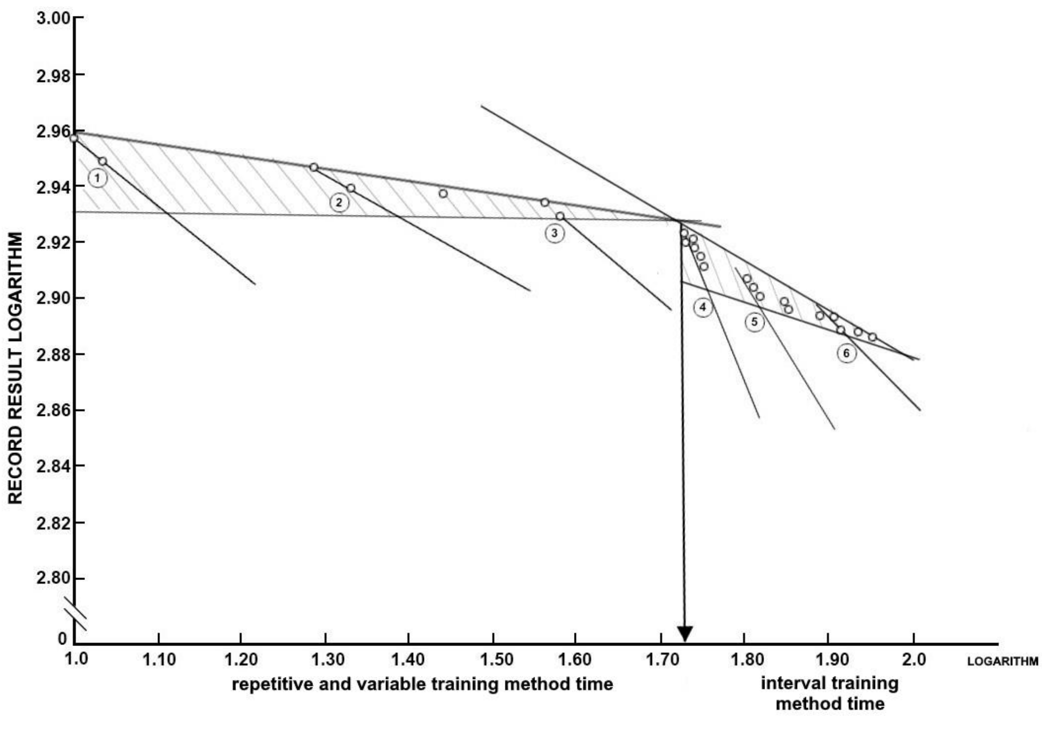
It is reasonable to assume that the main reason underlying the improvement of records is a change in the training methodology. Indeed, the first jump in the growth of records at a distance of 5,000 m (from the beginning of the century to 1924) is associated with the use of the continuous running technique at a given speed. In the next growth spike of records in the period from 1924 to 1938, Finnish champions made a great contribution, the training of which employed the method of repetition.

The period of 1939-1954 is associated with the use of a variable ("*fartlek*") training method (Swedish athletes). The next spike in record growth occurred in the 1950s, when the interval training method was used in the preparation of the strongest athletes. After this period, the time came when a training method was introduced in the practice of training leading athletes for long distances, combining long continuous running with high-intensity interval training (running on hilly terrain). The period of record growth, starting from 1977 to the present, is described by the integrated use of various forms of training: long continuous, variable and repeated run.

To analyse the growth of record achievements, we also applied the logarithmic transformation of exponential dependence. In the graph of Figure 2. (Figures 2 A – 2 B), where the logarithms of the record running time are compared with the logarithms of the year the record was established, an exponential curve corresponding to the equation $T_{rec.} = T_{in.} \cdot e^{-k \cdot t}$, turns into a straight line, the slope of which reflects the relative speed of improving records, associated with the effectiveness of the applied training method. On such a graph, the linear points of improvement in the records within each of the spikes ($T_{in.}$), and the points of the greatest deviation of the record results from the initial value are also linearly related. Straight lines drawn at these points form a space on the graph (shaded area), within which records can improve, which is determined by the training technique that dominates in a given period.



A



B

Figure 2. The growth curve of records in athletics running at 5,000 (A) and 100,000 m (B) over the 20th century on a logarithmic scale.

Two similar spaces are highlighted in the graph below – one of them includes the time until the beginning of the 50s (period of repetitive and variable training method), and the second – from the beginning of the 50s to the present day (period of interval training method). The intersection points of the straight lines bounding the spaces mentioned mark the time when the previously prevailing training method was replaced by a new, more progressive one. The first of these crucial stages occurred in the early 1950s, when the interval training method saw its introduction. The most intriguing is that the second major turning point happened circa 2000. This can reasonably be attributed to the upcoming change in the fundamental attitudes in the training of leading athletes in athletic running.

In connection with the latter circumstance, one cannot help but wonder what exactly will change in training, which concept of the training process will become dominant and will significantly improve world records and take athletic running to a new level. The answer to this question can be obtained proceeding from the data obtained in various physiological laboratories dealing with the issues of sports training.

The main factor determining the level of sports achievements in long-distance running is aerobic power, estimated by the maximum oxygen consumption (Robinson and Edwards, 1937; Astrand, 1955; Asmussen, 1965; Dill, 1967; Volkov, 1967; Wolkow, 1989). There is a reliable positive relationship between maximum oxygen consumption and athletic performance in long distance running (Volkov, 1967; Brandon and Boileau, 1987; Wolkow, 1989; Helgerud, 1992). Along with this, D.B. Dill (Dill, 1967), who conducted longitudinal studies on leading athletes, found that despite significant changes in training methods that allowed to increase record achievements, the maximum oxygen consumption among the leading runners of the world did not undergo much change. To this end, the author notes that the observed increase in records in long-distance running in our time is largely due to improved aerobic efficiency and an increase in the anaerobic abilities of athletes. Research conducted by N.I. Volkov (Volkov, 1967; Wolkow, 1989) confirmed the assumption made by D. Dill. In this regard, interval training has proven particularly efficient in improving the level of anaerobic capacity. Ergometric analysis of record curves indicated that with each new exponential spike in the improvement of results, an increase in the endurance coefficient is noted.

CONCLUSIONS

Ergometric analysis of record achievements in athletics running, successfully implemented in research practice in the 1920s, remains one of the most informative methods for determining the degree of development of energy-supplying processes in athletes specializing in individual running distances, including assessment of the efficiency of a particular training method, thereby opening up opportunities for targeted, scientifically sound impact on the weaknesses of the training process. Two ergometric procedures were most widely used: analysis of record achievements in running using the dependencies "*distance – time*" and "*speed – time*". It was established that athletes who train to overcome long running distances have better ergometric indicators characterizing aerobic performance: they are characterized by a higher coefficient of "*critical speed*" and a less pronounced decrease in the curve of the dependence "*speed – time*". And middle-distance runners were characterized by large values of power factor, which gives clear advantages upon performing intense muscular work.

The main reason underlying the improvement of records is a change in the methodology of training athletes. The data obtained by us in the analysis of record achievements in short distances and the forecast of records for these distances allowed to distinguish four stages throughout the history of record achievements in athletics, within each of which a radical reorganization of the applied training methodology occurred.

AUTHOR CONTRIBUTIONS

Author 1: Evgeniia O. Panova collected the data for figures and engaged in the selection of literary sources. Author 2: Elvira A. Lazareva performed, conceived and designed the analysis and wrote the paper, and also approved files and supervised the entire research process. Author 3: Ivan M. Kuptsov corrected stylistic flaws in the article, proofread the article and made all the necessary edits. Author 4: Natalia V. Valkina contributed data and analysis tools for study, and also involved in compose of figures based on collected data. Author 5: Vladimir V. Vavilov conceived and designed the analysis, and also collected the necessary theoretical information from literary sources.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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