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MODERN METHODS OF FATIGUE ASSESSMENT

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Purpose: to determine the general and modern methods of fatigue assessment. **Materials and methods:** analysis and generalization of scientific and methodical literature on the topic of study of fatigue processes; generalization of experience of practical work of the coaching contingent working with children in groups of dancesport; modified method of M.Ya.Breitman's clinical anthropometry; natural pedagogical experiment, methods of mathematical statistics and mathematical modeling.

Results: it should be noted that the improvement of information technology and the use of more efficient electronic devices allows for more promising development of mathematical modeling, provided its application in theoretical and practical studies of various processes in the human body, including processes such as fatigue. Therefore, in the further process of diagnosing the stages of fatigue, it is possible to apply mathematical models that already exist, as well as to continue the search for other options (in particular, using the theory of self-organizing systems).

Conclusions: the application of existing theories of fatigue makes it possible to consider the variety of causes of fatigue in the human body in terms of physiology. Understanding the causes of the fatigue process allows to develop systems that can restore the human body, using the possibility of additional feeding with the necessary substances for activity or imposing restrictions on the intensity and timing of actions. For more effective diagnosis of the degree of fatigue process, it is possible to use

methods of mathematical modeling and forecasting, as well as consideration of the fatigue process in terms of stability of selforganizing systems (including applying the Volterra equations, flow cultivator). Modern research methods of using mathematical apparatus and information tools allow for better and faster processing and analysis of large data sets.
Keywords: fatigue, fatigue theories, mathematical model, Breitman method, dancesport.

Introduction

The level of modern training of sportsmen provides for the increase in physical and mental loads, which in turn will increase the degree of fatigue. The ability to overcome the fatigue that occurs in the process of competitive activity largely leads to the achievement of sports results.

Significant loads withstand by sportsmen require an intensive search for means to resume their working capacity in the conditions of optimizing the training process, as well as in preparation for competitions and during their conducting. Therefore, knowledge of the patterns of fatigue development and the resumption of the sportsmen body is of important theoretical and practical importance.

Among the most common manifestations of the state of fatigue, there is a decrease in muscle strength and endurance, a deterioration in the coordination of movements, an increase in the energy value of the same work, a slowdown in the speed of processing information, a deterioration in memory characteristics, attention, a feeling of discomfort, and a rejection of activity.

There are many formulations of the fatigue period. “Fatigue” is a special type of functional state of a person, which temporarily occurs under the influence of prolonged or intensive work, which is accompanied by a decrease in its effectiveness.

Several aspects of the fatigue problem stand out: nature of fatigue; diagnostics; forecasting; ways to fight against fatigue and stimulate working capacity.

The purpose of the research is to determine the general and modern methods for assessing fatigue.

Material and methods of the research

The work was performed on the basis of the sports club “Ideal”. Dancers in the number of 20 sportsmen, who are engaged in dancesport at the initial training stage, took part in the research. In solving the tasks, the following methods were used: analysis and synthesis of scientific and methodological literature under the topic of studying fatigue processes; summarizing the experience of the practical work of the coaching contingent, which works with children in sports dance groups; modified method of clinical anthropometry of M.Ya. Breitman; pedagogical experiment, methods of mathematical statistics, and mathematical modeling.

Results of the research

Historically, since the middle of the 19th century, many physiologists were interested in this topic. So, at this time such theories were defined:

1) The fatigue theory of M. Schiff (1868 p) - was based on the fact of the decrease in glycogen reserves in muscles that were exhausted.

2) The poisoning theory of E. Pfluger (1872) - associated the development of fatigue with unacceptable (poisonous) growth of metabolic products in muscles, in particular lactic acid.

3) The strangulation theory of M. Fervorn (1901) – the model for the development of fatigue due to the lack of oxygen in muscles was proposed.

V.V. Rosenblatt (1975) identifies this group of theories and marks as a group of humoral-localist theories that are based on researches of isolated muscles. Another group of theories, called by V.V. Rosenblatt as the central-nervous theory, connects mechanisms of fatigue with structures of the central nervous system. One of the founders of the central nervous theory of fatigue is A. Masso, who published the monograph “Fatigue” in 1893. This work presents the results of the research of muscular activity on a person and the shown role of central mechanisms in the formation of a state of fatigue.

Rosenblatt V.V (1975, 1983) identifies four main areas within the framework of the central-nervous theory.

1) The development of the first direction is primarily associated with the name of L.L. Vasiliev (1926) and M.I. Vinogradov (1935) - the leading role in the development of fatigue is assigned to the processes of inhibition in the central nervous system. The main factors contributing to this braking state are: working dominant attenuation, excessive afferent flow (a constant flow of nerve impulses that enter the central nervous system from sensory organs, which perceive information both from external irritants (extroreception), and from internal organs (interoception), which is directly dependent on the number and strength of the influence of irritants, as well as on the state – individual's activity or passivity) from working muscles and the effect on nerve centers of biochemical disorders in the blood that occur with active muscle work.

2) The representative of the second direction of the central nervous theory of fatigue was V.A. Levytskyi (1926) - with his theory of the development of the imbalance occurs in the interaction of the cortex of large hemispheres and centers of the autonomic nervous system. At the same time, vegetative activity support centers act as protective concerning the cortex and performing organs, sending brake signals to them, thus preventing the possible undesirable consequences of excessive physical activity. In other words, we are talking about "conflicts between conscious - strong-willed and autonomic-vegetative spheres" (V.V. Rosenblatt, 1983, 230 p.).

3) The third direction, which has the largest number of supporters, is developed from the position of the theory of dominant of A.A. Ukhtomskyi (1934). At the heart of fatigue, proponents of this approach see a violation of the coordination of processes that ensure an active state, and primarily in the central nervous system.

4) In the fourth direction, K.Kh. Kecheiev (1949) considers the development of muscle fatigue in connection with the weakening of the adaptation-trophic influence of the sympathetic on the somatic nervous system.

V.V. Rosenblatt himself proposed the central cork theory of human muscle fatigue. He believes that the primary link of fatigue should be sought in the cork limb of the motor analyzer while noting that the shift in all other links of the musculoskeletal system and other systems of the body is secondary. According to

V.V. Rosenblatt, changes that arose for the second time in autonomic, endocrine, and muscle systems, and are accompanied by changes in biochemical parameters, in turn, affect the primary link of fatigue (motor cortex and motor centers of the central nervous system), enhancing the state of the latter one.

Vinogradov M.I. (1958, 1966) also identifies two types of fatigue - primary and secondary. According to M.I. Vinogradov, primary fatigue, which acutely occurs, develops as a result of unusual or excessive work, and secondary (slowly develops) - as a result of although usual, but long-term activity. It provides less value to biochemical shifts in the working body, linking the development of both primary and secondary fatigues with disorganization processes mainly in the central nervous system.

I. M. Siechenov (1952,1955), as the founder of the theory of nervism, made a significant contribution to the physiology of work not only by the one who substantiated the role of the central nervous system in the formation of fatigue during physical work but also by the fact that he was one of the first (after A. Masso) who used the shoulder Ergograph to study the processes of muscular activity, which imitated the work of a hand during “sawing” movements. It was with the help of Ergographer, I. M. Siechenov were obtained well-known facts of a faster resumption of the functioning of a tired hand in conditions of load on other muscles. This phenomenon was designated as the phenomenon of “active” rest. I.M. Siechenov connects the phenomenon of “active” rest with the activation of tired centers with the flow of afferent impulses from other muscles, that is, through other nerve centers.

The subsequent research in this direction was also carried out by I.V. Muravov (1055-1991). In Ukraine, under his leadership, programs of active recreation, industrial gymnastics, as well as physical education for people of different ages were developed.

It is usual to distinguish two main types of fatigue - physical and mental, although such a separation is quite conditional.

Also, some sources describe other types of fatigue - general, local, muscle, visual, mental, and so on. Highlighting these types of fatigue, the brightest shifts are

noted in those systems that are most “loaded” in the process of work. The limits between the indicated types of fatigue are conditional because it’s difficult to imagine the isolated functioning of individual systems in a holistic organism. However, such an approach is proved in terms of prevention and control of fatigue.

Fatigue may differ in severity. It is customary to distinguish four degrees of fatigue: from little expressed (the 1st degree) to very expressed (the 4th degree). The attribution of the state of fatigue to one or another group depends on the severity of shifts of the corresponding physiological, psychophysiological, and other indicators of activity.

Based on existing ideas about the causes, mechanisms, and consequences of fatigue, it is customary to distinguish several approaches to its diagnosis:

- performance assessment;
- assessment of the state of physiological systems of the body;
- assessment of psychophysiological characteristics;
- subjective assessment of the state.

Researchers usually use all of the listed approaches to fully diagnose fatigue. This is due to the understanding of the nature of the state of fatigue and, first of all, to the fact that fatigue is based on the non-coordination of functional systems. One shouldn’t forget about the role of fatigue as a protective reaction to the excess load of the body.

Considering this issue, A.O. Navakatikyan (1993) notes that fatigue and working capacity are closely interconnected, and, adhere to certain terms of decrease of working capacity under the influence of work, characterizes the degree of fatigue. He proposed a conceptual mathematical model in which the mapped foundations of the relationship of working capacity (P) and fatigue (Y) with labor efficiency (e), the nature of the work performed, including its aims (W), the conditions of the production environment (C), the state of physiological systems, which consist of subsystems I (information), E (energy) and M (motivation). Labor efficiency is determined by the formula:

$$e = W * C * I * M * E, (1)$$

where all indicators are expressed in relative values. Working capacity is assessed according to physiological and production parameters when performing a specific work (Ws) under the optimal conditions:

$$P = e_{max} = Ws * C_o * I_{max} * E_o * M_o, \quad (2)$$

where the indices "max" та "o" mark the maximum and optimal values of the functions respectively. At the same time, changes in working capacity between two points of time (t1 and t2) caused by operation reflect the degree of fatigue (Y);

$$Y = P_{t1} - P_{t2} \quad (3)$$

The proposed model can be used at optimal and stable levels of working conditions, motivation, and activation of systems. As these conditions aren't most often met, then the standardized indicators C, E, I, and M. should be used. The author believes that the proposed approach allows to a certain extent to more correctly interpret many of the available data on the problem of fatigue and working capacity.

The huge material was accumulated regarding disorders in the body systems during the development of fatigue in the physiology of labor. The most fully studied cardiovascular, respiratory, musculoskeletal, excretory, endocrine, and central nervous systems. Metabolic and energy indicators, a function of oxygen supply, and dynamics of blood indicators are widely used to diagnose the state of fatigue. Features of neuroendocrine regulation and intersystem interactions are less studied.

The assessment of the state of systems and functions in the dynamics of working capacity and fatigue dynamics has two main aims. The first is to detect the degree of implementation of the reserve capabilities of the system in conditions of labor load. It's known that different systems have different adaptive capabilities. The second aim, which was to study the behavior of systems in the process of work, is to determine "the factor that limits", which leads to a significant decrease in working capacity, to the development of fatigue. The function or system that has the greatest workload during operation is most often the "factor that limits". In this regard, the practice of labor physiology adopts the principle of the previous analysis of activities

in order to identify the functions of the most “loaded”. This makes it possible to create a reasonable minimum of directions and a set of research methods.

Historically, this approach to assessing the functional state, including fatigue, arisen relative to professions where information interaction between human beings and the environment prevails. Performance indicators of analyzers (visual, auditory, tactile), integral functions – visual-motor and audio-motor coordination, regulation of motor acts, processing of information, memory, attention, decision-making process were studied. Recently, psychological methods have been increasingly used in the physiology of labor - testing personality properties, psychological processes.

Diagnostic value is only those indicators that show a disturbance in systemic reactions during the activity. It’s important to evaluate intersystem interactions, especially in the field of central regulation of motor and visceral functions.

There are the most controversial thoughts about the possibility of using a feeling of fatigue as indicators of fatigue, but they reflect rather unsuccessful attempts at modern psychology than the present state of affairs. Still, S.G. Gellerstein (1926) noted that subjective manifestations are nothing more than the display of objective processes in human sensations or consciousness. On the other hand, a feeling of fatigue (subjective assessment) can also appear in conditions of light, not stressful labor, next to its absence, most often, with a fairly significant workload. This indicates that the causes of fatigue don’t always coincide with such when a state of fatigue develops.

The questionnaire doesn’t quantify the results. This disadvantage is overcome with the help of methods of subjective assessment of the state on a scale. The person tested correlates his feelings with a number of polar signs, for example: “tired - not tired”, “cheerful – sluggish” or with individual statements such as “weakness”, “rested”. The results of the responses are compared to an assessment scale compiled by empirical or expert means. The status level is diagnosed in points. In the known WAM test proposed by S.A. Doskin et al. (1973), 30 pairs of polar value signs are proposed to the test. The person tested should evaluate his condition for each of the pairs of signs on a seven-point scale. The conclusion about the state is given by the

average scoring of well-being, activity, and mood (hence the name of the test - WAM), and the nature of the relationship between them.

There are different modifications of this test regarding individual activities. It should be noted that the subjective assessment of the state of fatigue is considered only as of the previous stage of the study of the functional state. A complete picture of the state can only be drawn up taking into account all approaches that determine the “active” state of a person.

At this stage of the development of science, a certain limit has already been reached on the possibility of revealing the research problem from the point of view of physiology. Currently, the task of identifying methods for determining the state of fatigue and searching for methods for resuming the human body system is differentiated. There are separate fields of science in which research is based on fundamentally new research methods. The use of mathematical modeling methods leads to the process of integrating knowledge from different fields of scientific research, thereby forming the only theory of the development and formation of self-organization processes.

If we accept that the human body is the system that self-organizes and adds to this the capabilities of mathematical modeling and forecasting the development of systems, then we can get a new approach to methods for assessing fatigue.

Several mathematical methods for analyzing empirical data developed at the end of the 19th century deserve special attention, which includes:

1. The method of A. Quetelet “average person structure”. The essence of the method is that each link of the body (to the same age and sex) is taken in its absolute dimension and the average value of its size is obtained. They give the average values of a person combined into a single whole. In practice, the reusable accumulation of similar is manifested in a clearer expression of the structure characteristic of the corresponding residence environment [4].

Any parameters are taken separately, such as body length, weight, individual biokinematic link or body organ, or the type and mode of their activity, lead to the average value of the structurally functional construction of the “average person” as

the most pronounced, relative to all directions of the three-dimensional representation of the body. If the “average person” is taken as the standard or limit of the reference (conditional zero) and used to analyze the considered object, then you can determine a measure of deviation from the “derived norm or conditional zero”. When compiling the relations of each of the compared body parts among themselves or each of them as a part to the whole, the ratio coefficient loses dimension and compares characteristics and is expressed in parts of one or in percentage, or in established units of normalized space.

In this case, the structure of the “average person” as a unit of measure displays the qualitative structure of the image structure. The uniform blur of the contour “Middle” towards the proportional measurement ±% from X constitutes the zone of the universality of the “middle” structure. Any deviation of the real image from the standard in any direction with the clarity of the expression and the distance of its manifestation is a pathological representation of something that violates the relationship of other parts of the whole. Within the limits of the manifestation of the versatility of the functioning of each of the parts of the whole, their stress and wear occur, which determines the duration of maintaining an equilibrium stable ratio.

Practically, the method of the “average person” revealed the essence of a factor that strengthens a holistic structure, which consists of a “universal” equalization of the distribution of energy-mass exchange between the constituent components of an entire organism and a “specialized” distributive energy mass exchange. However, at that time, this discovery didn’t find a proper understanding of its entire significance due to insufficient preparation for its perception.

2. The method of F. Galton, associated with the structure of “collective photography”. The essence of the method of “collective photography” in its content is close to the method of A. Quetelet in the structure of the “average person”. In this case, according to the established rule of this process, the total value of a large number of photographs is superimposed on one photographic plate. As a result, the features of the characteristics that are mostly found in the compared lens are drawn out. By the measure of distance from a clear image, blur increases, which

proportionally loses clarity to the output circuit. This can be characterized as a "universal" measure of the persistence of the image, which is observed in the process of comparing the proportionality of a large number of photographs. Also, in addition to the clear image of the standard, some distortions of it as an increase, in contrast, were quite pronounced [8].

Using the method of Galton, Sheldon, when studying thousands of photographs, noted that such distortions have a certain orientation in three strictly defined directions with a clearer blur among these directions.

Almost simultaneously with the method of Sheldon, the method of clinical anthropometry by M.Ya. Breitman appears. This method introduced the classification of somatotypes taking into account hormonal ratios in the humoral medium of organisms and the influence of this composition on the formation of somatotype structure. The introduction of fifteen elements of the construction of the somatotype depicts various variants of his constitutional structure and the accompanying nosological interdependence of the structure of the corresponding type of structure, as well as a measure of the viability of a particular somatotype, to the environment of his environment [1, 2].

M.Y. Breitman introduces into the basis of clinical anthropometric diagnostics the separation of the qualitative structure of the formation and the general characteristic of the absolute size of the body.

The modification of his technique consists in establishing not only the structure of the relations between the partial sizes of the body to the total length of the body but also their rank of value, as well as the order of passing the value in the ranked series. This makes it possible to establish the features of biological development and its deviation from the standard, both in the qualitative direction and in the magnitude of their manifestation.

The possibility of changing the value of any parameter and its order of the ranked series of interacting functional structures in the structure determines the level of universality of the holistic structure of the organism in ensuring adaptive behavior. In some cases, this is interpreted as an indicator of the plasticity of an integral system,

which has the characteristics of the speed of this process, the strength of its severity, and the expansion limit. These processes are most effective in the area of indicators of “average person”.

The level of universality manifestation is determined by the possibility of changing the order limits in the ranked structure of share participation of each of the component components within the limits of possible variation of its functional activity from the maximum permissible minimum to the maximum possible maximum. The range of boundaries from minimum to maximum determines the variability of the change in the structure of the restructuring of the ranked series, which displays the qualitative rebirth of functional activity.

The modification of this method made it possible to find a new opportunity regarding the definition of the individual's somatotype and obtaining a code from a number of primes, after which you can determine a structure of fifteen indicators.

It should be taken into consideration that the metabolic processes of human activity take place in the general internal environment of the body, but with different directions of expression. This feature is manifested in the essence of anabolic and catabolic components of metabolism, which gives rise to a complex multi-component structure of relations “request-pleasure” of the whole complex of “flowing Chemostats” or “cultivators”. The performance of any activity is associated with energy consumption, the potential of which requires systematic replenishment. Regardless of the level of this process, its mechanism is represented by the flow system of energy-mass exchange. Such a process leads to a saturation of the need for them. The optimal state meets the equal demand and satisfaction of this demand. Such dependence, in addition to the quantitative relationships “demand-pleasure”, has a characteristic of the speed of its flow.

The main task of maintaining the persistence of the integral mutual relations of these phenomena in the flow system is to synchronize their interaction.

In general, this process found its mathematical description in the expression of the mathematical model of Volterra-Lotka, which describes the relations of “pleasure–demand”. Subsequently, Kolmogorov extended this model to an unlimited

number of interchangeable processes that have a consistent interaction “demand-pleasure”.

Thus, the main characteristics in the flow systems, which, first of all, act: blood, respiratory, intestinal-gastric system, there is a volumetric flow of the initial mass exchange, its concentration, the rate of transformation of the mass exchange material, the level of saturation with metabolic products, the coefficient of the economy of using the initial mass exchange.

In fact, the question can only be about the circulatory system as a flowing “Chemostat”. All others can be considered as specialized organ-making or flow “Chemostats”, in which differentiated metabolic processes are carried out with completely different directions of anabolic and catabolic processes. The whole variety of these relationships in the system of a holistic organism is described by the equations of the flow “Chemostat”, which in some cases are defined as a flow cultivator.

When the biological maturity limits are reached as an indicator of the mastery of the medium interaction (the possible level of adaptation behavior complexity), which determines the viability of the integral system, its subsequent equilibrium state depends on maintaining the accuracy of synchronizing the specialized “Chemostats” on the energy supply flow. The limit in energy supply leads to the emergence of the highest cost-effectiveness of the structure of the dynamic stereotype of adaptive behavior. Violations of the correspondence between the statistical structure of the environment stay and the statistical stereotype of individual adaptive behavior lead to energy costs that cannot be replenished beyond the total requirement, which consists of the need to eliminate debt and the need to replenish the exchange in order to maintain the baseline level of vitality of a holistic organism.

Conclusions / Discussion

The results of the analysis of the existing theories regarding the causes of fatigue as a physiological process confirm the authors' opinion that the problem of timely diagnosis of the beginning of this process in the human body doesn’t lose its

relevance [4, 6, 8]. Especially when it comes to the process of training for the highest sporting achievements.

Using the existing fatigue theories makes it possible to consider the variety of causes of the fatigue process in the human body from the point of view of physiology.

Understanding the causes of the fatigue process allows you to develop systems that can resume the human body, using the possibility of additional feeding with the necessary substances for the activity or introducing the restriction on the intensity and time of action.

For more effective diagnosis of the degree of fatigue process, the possible use of mathematical modeling and prediction methods, as well as consideration of the fatigue process from the point of view of the persistence of systems that are self-organized (in particular, the use of the equations of Volterra, the flow cultivator). Modern research methods using the mathematical apparatus and information means to give the possibility for better and faster processing and analysis of large amounts of data.

The prospects for further research. It should be noted that the improvement of information technologies and the use of more efficient electronic devices provides an opportunity for a more promising development of mathematical modeling, provided its application in theoretical and practical studies of various processes in the human body, and in particular such a process as fatigue. Therefore, in the subsequent process of diagnosing fatigue stages, you can use mathematical models that already exist, as well as continue to search for other options (in particular, using the theory of systems that are self-organized).

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