

CRITERIA OF ATHLETE NEUROMUSCULAR SYSTEM RESERVE CAPACITIES DURING PERFORMANCE OF SPEED-STRENGTH WORK

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Abstract. The work presents complex methods of simultaneous registration of electric activity of the lower extremity muscles and efforts developed in the process of jumping test performance to exhaustion with revealing structural changes of muscles, their capillaries and other energy supply elements. Methodology reveals inborn predisposition of the system of execution and management of locomotion to loads of different character as well as the level of neuromuscular system reserve capacities in the process of long-term adaptation to physical loads.

Key words: efforts, electric activity of muscles, jumps, athletes, work capacity, fatigue

Introduction

The modern system of top level athlete preparation should be initially based on the account of genotypic and phenotypic factors, their interrelation for improvement of the body reserve capacities, its individual systems, providing high level of special physical work capacity.

High level of special physical work capacity and the efficiency of competitive activity of athletes are determined to a great extent by their physical and functional fitness, closely interrelated and correlated with other components of fitness general structure (Mishchenko 1997; Radzievskii et al. 2002; Rishna et al. 2014).

As the functional reserves (FR) are differently determined by genotypic and phenotypic factors and manifested under various regimes of muscular activity, in individual systems, in various sports events, at different distances (Tucker et al. 2011; Mishchenko 1997; Shchegolkov et al. 1990, 1993), there is no common universal method of their revealing and quantitative estimation criterion; they are hardly diagnosed and compared, i.e., they are specific.

In this regard search for and elaboration of the most adequate, specific methods of their determination, evaluation and interpretation in the process of body performing differently in intensity, volume and direction work, is quite important from the methodological point of view.

Neuromuscular system (NMS), being an executive morphofunctional and metabolic component of various functional systems, represents one of the major objects for studying FR in different sports events.

One of the most common, relatively simple and accessible methods of diagnosis of NMS state during performance of strength and speed-strength work are different variants of the jumping test (Bosko et al. 1983; Shchegolkov et al. 1990; Yaschanin 1983). However, most of the jumping methods of testing suggested by the authors are either short-term or performed in the form of single jumps (Nahdiya 2013; Rishna et al. 2014). The above does not allow complete uncovering of NMS reserve capacities, providing high level of physical work capacity during performance of work of different character and at rather prolonged character of muscular activity.

In this regard, in order to determine the criteria of athlete neuromuscular system reserve capacities regulating efficient performance of speed-strength work, we have elaborated and evaluated the method of complex testing of NMS state during performance of jumping test (Shchegolkov et al. 1990, 1993).

The objective of the given study is to determine criteria of athlete neuromuscular system reserve capacities during performance of speed-strength work.

Methods of studies

Vertical jumps of maximum height performed on tensodynamometric platform until the state of steady work capacity decrease were used as testing load. The following parameters were recorded: a) electric activity of the lower extremity muscles with utilization of epicutaneous lead of electromyogram (EMG); b) impulse activity of individual motor units (MU) with usage of stuck in needle electrodes; c) efforts developed during taking off on the tensodynamometric platform (Figure 1).

The character of load performance (duration, intensity) models specific activity of an athlete in a definite sports event.

Application of stuck-in needle electrodes has permitted to study instant frequency of recruited MU under conditions of increased speed of muscle contractions. Impulse activity of MU of tibialis anterior of the leading extremity has been investigated under conditions of its strict fixation (Yaschanin 1983). Subjects, who according to data of jumping testing were evaluated as having predisposition to practicing "speed" sports events, have been subjected to the method of local electromyography. This part of studies was conducted a week after jumping testing; it should be mentioned that only "speed" athletes (n = 3) and individuals with the highest degree of predisposition to practicing sports events with manifestation of general endurance (n = 3) took part in this fragment of complex studies.

The control group included persons characterized by an average level of speed endurance manifestation.

A lack of warming-up before jumping test performance allowed relatively fast and "pure" manifestation of genetically determined predisposition of an athlete's body to activities of "explosive", speed-strength, or endurance type.

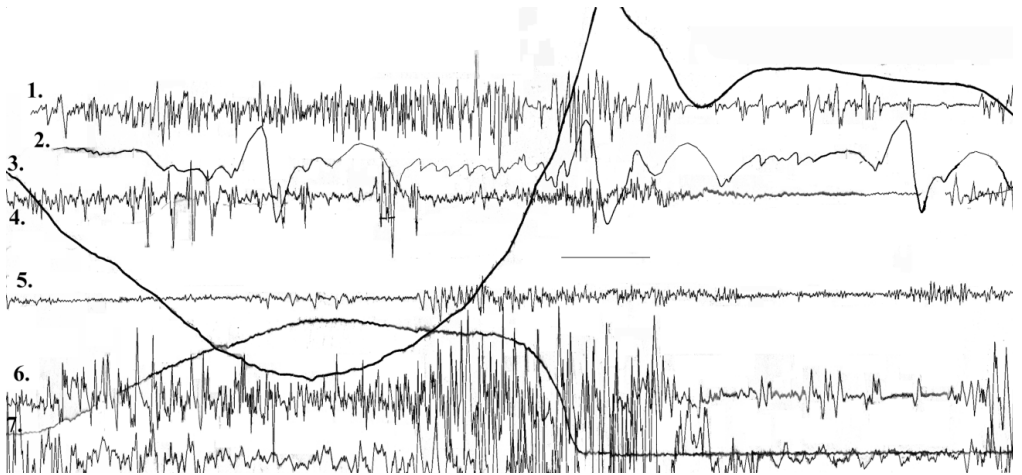


Figure 1. Electric activity of the muscles of the lower extremities (1, 4, 5, 6, 8), heart (2), knee joint goniogram (3) and effort developed (7) during jumping test performance on the tensodynamometric platform. 1, 4, 5, 6, 8 – electromyograms of: 1 – quadriceps muscle of left thigh; 4 – tibialis anterior; 5 – gastrocnemius muscle; 6 – quadriceps muscle of right thigh; 8 – biceps femoris.

Immediately after the jumping test, in persons with the “best” ($n = 3$) and the “worst” ($n = 3$) results, structural changes of muscles, their capillaries and a number of energy supply elements have been revealed by means of biopsy, histochemistry, cytochemistry, light and electronic microscopy of external head of quadriceps femoris (QF) of the leading extremity (Shchegolkov et al. 1993).

24 top-level freestyle and Greco-Roman wrestlers participated in the experiment.

Results of studies

It has been revealed in the course of studies that electrical activity and interrelation of the lower extremity muscles of athletes are closely connected with the values of developed efforts during jumping, degree of developed fatigue, and body morphofunctional status.

Revealed coefficients of pair correlations (Figure 2) reflect the linear character of relationships of biceps femoris (BF), right quadriceps femoris (rQF), left quadriceps femoris (lQF), gastrocnemius muscle (GM), and tibialis anterior (TA), between each other and the developed effort (F_{max}) in athletes – both at the beginning of work ($n = 24$) and before the refusal to continue ($n = 21$). It has been also noted that QF makes the greatest partial contribution to the amount of developed efforts and the height of performed jumps.

Dispersion analysis has demonstrated that in athletes with powerful explosive contractile capacities of muscles providing the highest height of jumps, the contribution of QF to developed efforts varies from 76,2% to 88,2% ($P < 0,001$).

It should be stressed that its greatest contribution has been noted in the development of accelerating force (G) which, in turn, correlates statistically significant with the height of jump ($r = 0,857 \pm 0,15$, $P < 0,001$). Determination coefficient (r^2) indicates that the contribution of accelerating force to the height of jump during performance of the given test constitutes $73,4 \pm 2,25\%$ ($P < 0,001$).

Usage of muscle biopsy, histochemical and submicroscopic methods has allowed to reveal different structural and functional changes in skeletal muscles, which characterize reserve capacities of NMS in the process of adaptation to physical loads.

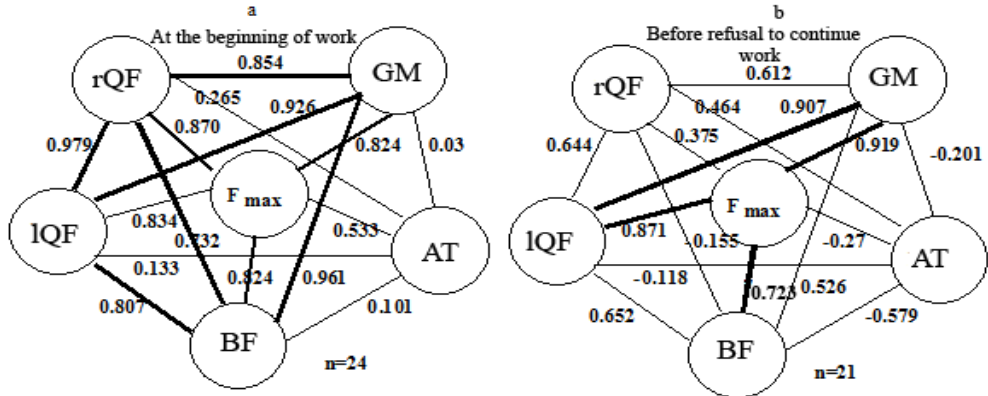


Figure 2. Diagram of relationships of the lower extremity muscles between each other and the developed vertical effort (F_{max}) at the beginning of testing (a) and before refusal (b) to continue work (in the process of development of apparent fatigue).

Under conditions of optimum training loads, the number of sarcomeres in myofibrils increases as well as the length of myofibrils, the activity of contractile apparatus enhances, the number of large mitochondria grows, canaliculi of sarcoplasmic reticulum become wider, and the level of vascularization increases. The above contribute to more active functioning of muscle energy supply mechanisms with manifestation of speed-strength endurance.

At such state of muscle structure, high stability of their work capacity has been observed which was confirmed by the stability of developed efforts, electric activity of the lower extremity muscles and height of jumping under stable conditions.

The abovementioned morphofunctional peculiarities in reorganization of muscular system should be referred to positive effects of adaptation, reflecting improved functional reserves of NMS in case of sports specialization correspondence to inborn morphofunctional features of athletes' muscles.

Unsatisfactory response to testing load (negative effects of adaptation) has been observed in athletes in whom the direction of training process did not correspond to inborn contractile features of skeletal muscles as well as in athletes overloaded by intensive training sessions.

Work to fatigue is accompanied by "redistribution" of activity and weakened correlation of studied muscles between each other and the developed effort (Figure 2) along with leading role of QF at different phases of motion, "delay" of electric activity increase of the leading muscles to maximum values as compared to stable state, decrease of efforts and jumping height during take-off.

The most peculiar signs of fatigue in athletes, whose muscles are predisposed to endurance activity, are: decrease of maximum and accelerating force, prolongation of electric activity and gradient of EMG amplitude increase of loaded muscles during accelerating force development, significant increase of electric activity dependence upon accelerating force (Figure 3).

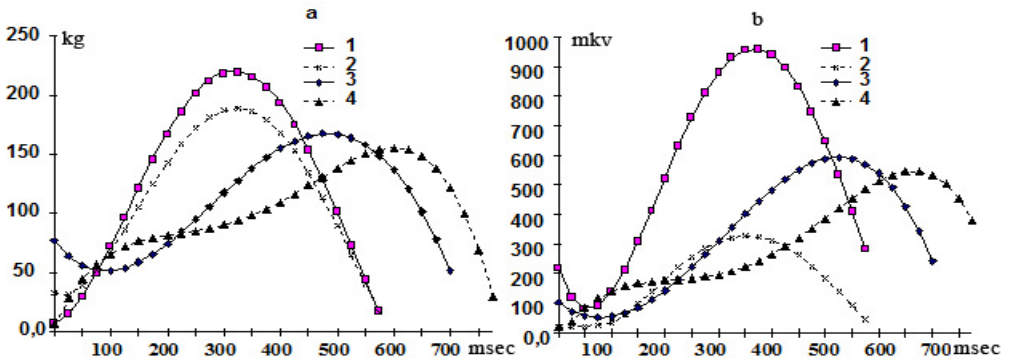


Figure 3. Developed efforts (a) and electric activity of quadriceps femoris (b) in athletes with high (1, 2) and low (3, 4) explosive features of muscles during execution of jump at the beginning (1, 3) and at the end (2, 4) of testing.

The most peculiar signs of fatigue in athletes, whose muscles are genetically predisposed to speed activity but have low speed endurance, are: significant alteration of the ratio of indices of high and low jumps in favor of the latter, decrease of maximum and explosive effort values, reduction of muscle electric activity amplitude.

The analysis of data of MU recruiting and de-recruiting has shown that their activation threshold was the lowest in subjects predisposed to speed activity as compared to those predisposed to endurance activity and the control group. MU de-recruiting in subjects predisposed to speed activities occurred at higher levels of strength manifestation as compared to those with predisposition to endurance type of activities (Figure 4).

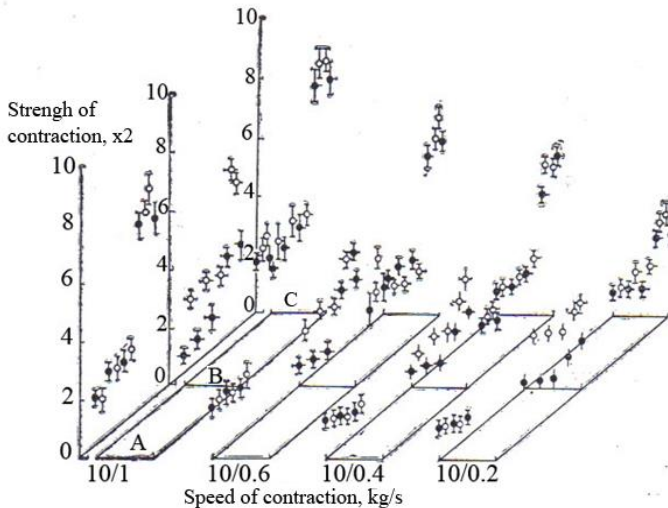


Figure 4. The level of muscular strength at which MU are recruited and de-recruited under conditions of increased gradient of contraction strength of anterior tibialis muscle (needle lead of EMG); indices for five successively recruiting MU are presented: A – “control” group; B – subjects predisposed to practicing speed sports events; C – subjects predisposed to endurance events; ● – contraction; ○ – relaxation.

There is every reason to assume that some discrepancies of MU impulse activity may be determined by differences of afferent activation by various morphofunctional indices of MU being manifested under indicated conditions of muscle contraction (Figure 4).

It is known that for the stretch reflex, of major importance are the primary endings of muscle spindles which cause excitation impacts upon alpha-motoneurons monosynaptically (Granit 1970; Fitts 2004).

One may assume that these differences of MU impulse activity may be also polysynaptically influenced by these endings (Enoka and Gandevia 2006; Enoka and Douchateau 2008; Yaschanin 1983).

The results of studies indicate that during transition from the state of functional rest to a certain level of muscle contraction with different velocity, the frequency of MU impulses is significantly higher relatively to the stabilized level of isometric contraction.

The frequency of impulses of different MU was determined in our studies according to duration of the first, the second and the third interpulse interval (II) (Figure 5).

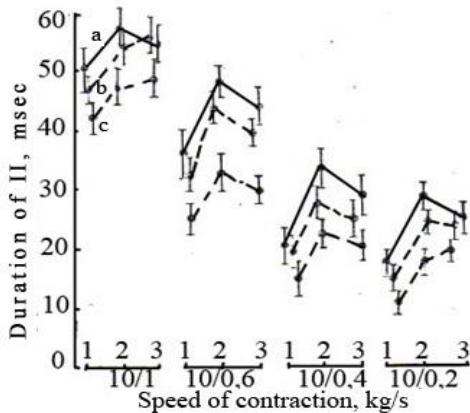


Figure 5. Quantitative indices determined for three first II, recruited by the first MU: a – subjects with predisposition to endurance; b – control group; c – subjects with speed predisposition; needle lead of EMG (anterior tibialis muscle).

The findings show that along with the increase of muscle contraction velocity, the duration of the first II of recruited MU has decreased to a greater extent in subjects predisposed to “sprint loads” ($p < 0.05$).

As a rule, the second interpulse interval during such muscle contractions was longer, followed by II of shorter duration. In some cases, at a gradient of accelerating force equal to 10 kg/0,2 s, series of MU impulses have been observed, which was also peculiar for subjects with speed predisposition.

During MU recruiting (of slow – I type or intermediate – IIB type of contraction) the duration of the first, the second and the third interpulse interval «b» may not differ significantly. There is every reason to assume that MU recruited with high instant frequency preferentially form high potential of “explosive” muscle strength. Higher instant frequency of muscle MU impulses in subjects predisposed to “speed” loads may be determined by high percentage of MU of fast contraction type (II A type).

Comparative data of EMG demonstrate that II duration during motor task execution in the form of gradient of muscle contraction of 10/kg/s and 10/kg/0,2 s is different in subjects with different motor predisposition (Figure 6).

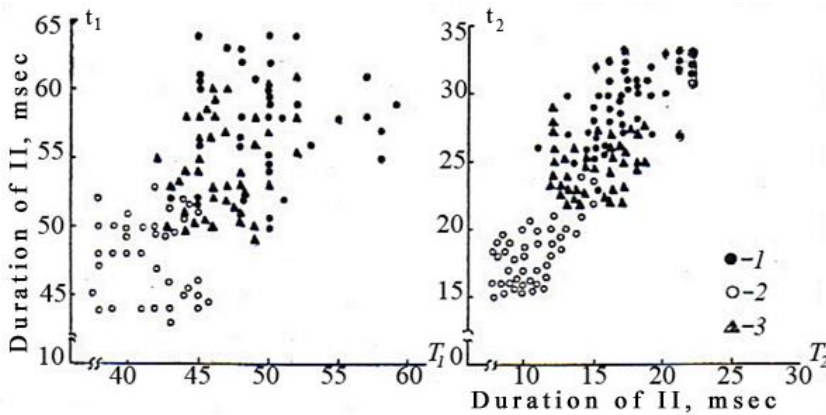


Figure 6. Ratio of the first II (t_1) and the second II (t_2) during developed muscle conditions of 10/kg/s and 10/kg/0,2s in subjects with different motor predisposition; ● – control group; ○ – subjects predisposed to speed loads; ▲ – subjects predisposed to endurance loads.

The shortest II have been noted for different MU recruited at the beginning of indicated motor task execution. One may assume that in persons predisposed to speed loads the threshold of MU recruiting under such conditions is lower as compared to that of other subjects. The above may be determined by the mechanisms of alpha-motoneurons activation, afferent inputs as well as processes occurring on the level of their axon hillocks.

It has been discovered that during fast reflex physical contractions even MU of slow type are recruited, reaching “plateau” of impulse frequency significantly later than low frequencies of MU of fast type. Instant frequencies at the moment of their recruiting are significantly lower as compared to MU of fast type.

Obtained data of instant frequency of MU impulses under conditions of increased gradient of muscle contraction (10 kg/1 s, 10 kg/0,5 s, 10 kg/0,4 s, 10 kg/0,2 s) demonstrate that only in few cases impulse activity of MU of anterior tibialis muscle is significantly higher with respect to other subjects (Figure 4).

It should be outlined that a routine procedure was applied to all subjects.

High instant frequency of MU impulses peculiar for the given muscle of some subjects may be indicative of predisposition to loads of speed character, whereas lower instant frequency of MU impulses predisposes to performance of muscular loads with lower speed.

The above suggestion may be confirmed by electromyographical indices of cutaneous EMG during jumping test performance (Figure 1) and biomechanical indices during performance of the series of multiple vertical jumps.

Discussion

Analysis of the results has shown that electrical activity and interrelation of the lower extremity muscles of athletes are closely connected with the values of developed efforts during jumping, and a degree of developed fatigue and body morphofunctional status.

Use of muscle biopsy, electromyography, histochemical and submicroscopic methods, has allowed to reveal different structural and functional changes in skeletal muscles, which characterize the reserve capacities of NMS in the process of adaptation to physical loads.

It is safe to assume that presented differences in impulse activity of MU are directly dependent upon their features and differences of afferent organization of their activity (Granit 1970; Enoka and Gandevia 2006; Enoka and Duchateau 2008; Jakobsen et al. 2012). Besides, it is quite possible that MU features in each genotype have been inherited beforehand and, probably, may be completely disclosed in the process of purposeful, individual and genotype optimum sports training.

Electronic microscopy has demonstrated that during the performance of work to exhaustion by athletes whose muscles are genetically predisposed to speed work but have low speed endurance, ultrastructure of capillaries are disturbed first of all, which is manifested in transcapillary failure, conditioned by swelling of nuclei and cytoplasm of endotheliocytes, and resulting in delay or even termination of circulation or disturbance of transcapillary transport from blood into interstitium at maintained blood flow in major vessels.

Simultaneously or after that muscle fibers move apart because of swelling, myofibrils are separated and sarcomeres are broken in different areas with their contractile threads being disintegrated. All these result in ultrastructural disturbances and dystrophy as well as steady decrease of work capacity. Structural, functional and energy reserves of muscular system also significantly decrease.

Applied complex methodology of simultaneous registration of electric activity of the lower extremity muscles and developed efforts in the process of jumping test performance to exhaustion with revealing structural changes of muscles, their capillaries and other energy supply elements, by means of biopsy, histochemistry, cytochemistry, light and electronic microscopy, reveals inborn predisposition of the systems of execution and management of locomotion to loads of different character as well as the level of NMS reserve capacities in the process of long-term adaptation to physical loads.

Conclusion

Revealed morphofunctional peculiarities of muscle adaptation and deadaptation to loads of different directions and features of decompensated fatigue manifestation represent important diagnostic criteria of NMS reserve capacities.

Indices of NMS morphofunctional state are important for scientifically substantiated selection and sports orientation, determination of the level of biological reserves in order to perfect inborn qualities, discovery of possible functional disorders at earlier stages or latent unfavorable states in order to prevent athlete body overload.

FR are determined by both the level of NMS morphofunctional state and physical qualities of an athlete, the degree and the character of their correlation both with each other and sports result, and special work capacity.

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