Original Article

Functional reserves and reliability of controlling stereotyped motions of different coordination structures in athletes during muscular activity

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Abstract.

Objective: determination of evaluation criteria for functional reserves and functioning reliability of the system of controlling stereotypically repetitive movements in different states during muscular activity in athletes - weightlifters and cyclists. **Material and methods:** Highly skilled athletes aged 20-28 years specialized in weightlifting and cycling participated in various studies. A complex methodology was used to study the mechanisms of controlling acyclic speed-strength motion and the morphofunctional status of the body of weightlifters. In accordance with the algorithm of the developed methodology, athletes performed vertical jumps of maximum height on a tensodynamometric platform to a state of persistent work capacity decrease. Developed efforts during jumping, electromyogram of the lower extremity muscles, and HR were recorded. To study the mechanisms of cyclic motion control, the methods of bicycle ergometry were used. In the process of bicycle ergometry, efforts in the pedaling cycle, heart rate, electromyogram of the lower extremity muscles were registered. **Results:** It was revealed that under stable conditions of controlling speed-strength and cyclic motions, a rigid, programmatic mechanism of motor regulation is manifested. With the stability of the external (kinematic) structure of the motions performed in different periods of work, only certain parameters of its regulation tend to change: muscular activity and intermuscular interactions. They are indicative of compensatory rearrangements in the internal structure of movements, which ensure the stability of their external structure in a steady state and in the phase of compensated fatigue. In the phase of decompensated fatigue, muscular activity changes significantly, intermuscular relationships are disturbed, physical work capacity decreases. The use of biopsy, histo-, and cytochemistry, light and electron microscopy allowed determining morphological changes in skeletal muscles in the dynamics of muscular performance manifestation in the training process of weightlifters. **Conclusions:** The leading criteria for the reserve capacities of the system of controlling stereotyped voluntary motions in athletes are: stability and reliability of maintaining the qualitative parameters of voluntary motions within the optimal range in various physiological states during muscular activity; power, interference immunity, efficiency and interchangeability of compensatory responses providing the functioning reliability of the system of motion control (control according to the principle of equifinality); increasing the role of the program mechanism in the system of voluntary motion control under stable conditions of its realization.

Keywords: athletes, motion control, functional reserves, load.

Introduction

The problem of the human body functional reserves (FR) is one of the most pressing challenges of systemic physiology, including the physiology of muscular activity and sports physiology. In the process of long-term adaptation to physical loads, morphological, metabolic, and functional adaptive changes occur in the body of athletes, which form the basis of their functional reserves and special work capacity [Mishchenko, 1997; Radziyevsky, Priymakov, Oleshko, Jashchanin, 2002; Lysenko, 2003; Bosenko, 2016].

The level of athletes' special work capacity is an integral criterion indirectly expressing their FR the components of which are morphological, metabolic and physiological reserves [Mishchenko, 1997; 2000; Radziyevsky, Priymakov, Oleshko, Jashchanin, 2002; Pryimakov, Eider, Omelchuk, Archipov, 2016].

The analysis of available information showed that in the works devoted to the methods of assessing the athlete body functional reserves, testing methods with cyclic physical loads were mainly used [Mishchenko, 1997; 2000; Lysenko, 2003]. They permitted the authors to quantitatively express the values of the work performed, calculate the values of the total functional potential and the ratios of its integral components [Mishchenko, 1990; 1997; Lysenko, 2003; Danko, 2004].

The authors determined the parameters of gas analysis, cardiac activity, the power of anaerobic and aerobic energy supply systems, the speed of working in and recovery processes, and the mobility of physiological

processes as informative indices of the functional capacities of athletes in various sports events [Mishchenko, 1990; 1997; Malinsky, 2000; Barreto, 2018].

The methodological approaches used allowed the authors to determine the partial contribution of each of the individual indices to the manifestation of the special work capacity of athletes in the process of biological monitoring, as well as to develop integral components determining their functional potential, such as anaerobic and aerobic power, mobility and economy of physiological processes [Mishchenko, 2000; Lysenko, 2003; Mishchenko, Lysenko, Vinogradov, 2007]. According to the authors, the integral components are the leading determinants of both special work capacity and sports results of athletes mainly specialized in cyclic sports events.

Similar methodological approaches allowed a number of researchers to develop integral components of athletes' FR in certain acyclic, including situational, sports events [Malinsky, 2000; Danko, 2004; Pryimakov, Iermakov, Kolenkov, Samokish, Juchno, 2016; Chistyakova, 2012].

However, given that situational sports events are characterized by a variable structure of movements, the exact quantitative characteristic and assessment of athletes' FR, and the mechanisms determining their sports result present challenges [Malinsky, 2000; Danko, 2004; Pryimakov, Iermakov, Kolenkov, Samokish, Juchno, 2016].

This is due to the fact that the functional capacities, the level of special work capacity in acyclic, coordination complex sports events are determined not only by the character of vegetative support, but also, to a large extent, by the specificity of muscular activity, intermuscular relationships, the efficiency of compensatory rearrangements in the system of motor control [Pryimakov, Kozetov, & Kryshkovetsas, 2009; Shchegolkov, Priymakov, Pilashevich, 1990; Pryimakov, Jashchanin, Shchegolkov, 2014]. Their manifestations are specific, difficult to diagnose, there is no single universal method for their identification and quantitative assessment criteria.

Sports result, both in situational coordination complex and cyclic sports events, heavily depends on the quality and reliability of adaptive rearrangements in the system of motion control in various states during muscular activity: during fatigue, the action of confounding factors and hindrances in changing non-standard situations [Pryimakov, Monogarov, 2000; Pryimakov, Kozetov, & Kryshkovetsas, 2009]. However, the assessment of adaptive rearrangements in the system of motion control under extreme conditions of athlete's activity is inadequately treated in the literature.

As shown in the early works of Davidenko et al. [Davidenko, Mozhukhin, Telegin, 1987], Golubev et al. [Golubev, Davidenko, Mozhukhin, Shabanov, 1987] and in our recent publications [Pryimakov, Shchegolkov, & Yashchanin, 2010; Pryimakov, 2011; Pryimakov, Iermakov, Eider, Prysiazhniuk, Mazurok 2020], the reserves of the system of athlete voluntary motion control are associated with the power and stability of coordination rearrangement mechanisms under extreme conditions of activity. However, the assessment of these reserve power requires improvement.

The stability of the mechanisms for maintaining the coordination structure of voluntary movements under conditions of strenuous muscular activity is one of the less studied problems of systemic physiology. The criteria and normative estimates developed by specialists for the diagnosis of athletes' reserve capacities in cyclic sports events [Mishchenko, 1997; 2000; Lysenko, 2003; Pryimakov, 2011], cannot be directly transferred to assess the functional capacities and special work capacity of athletes engaged in acyclic sports events and vice versa [Malinsky, 2000; Kolenkov, Priymakov, Pristinskij, Osipov, 2012].

This implies different methodological approaches to their assessment, management and improvement [Golubev, Davidenko, Mozhukhin, Shabanov, 1987; Davidenko, Mozhukhin, Telegin, 1987; Pryimakov, Iermakov, Kolenkov, Samokish, Juchno 2016; Bosenko, 2016; Pryimakov, Iermakov, Eider, Prysiazhniuk, Mazurok 2020].

Due to the insufficiently studied problem of the functional reserves of the motion control system and its significance for sports physiology and the theory of sports training, **the objective of this work** was:

- determination of the criteria for assessing functional reserves and functioning reliability of the system of controlling stereotypically repeated motions in different states during a muscular activity of cyclists and weightlifters;
- determination of the criteria for reserve morphofunctional capacities of weightlifters' neuromuscular system during speed-strength work performance until fatigue.

Material and methods.

Participants. The athletes of the national teams of Ukraine (24 weightlifters aged 20-28 and 22 cyclists aged 22-27) were examined.

Study protocol was approved by Ethic Committee University. The research was fulfilled in compliance with WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects (2013).

Procedure. To study the mechanisms of controlling acyclic speed-strength motion, a complex methodology that allows assessing the morphofunctional status of the body of weightlifters during speed-strength load performance was used [Shchegolkov, Priymakov, Pilashevich, 1990; Pryimakov, Jashchanin, Shchegolkov,

2014]. Athletes performed standing vertical jumps of maximum height on a tensodynamometric platform to a state of persistent physical work capacity decline.

The following parameters were registered in each athlete while performing jumps: a) electrical activity of the lower extremity muscles and heart; b) the efforts developed during taking-off from the dynamometric platform (Fig. 1).

Fig.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 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.

Structural changes in muscles, capillaries, and energy supply elements were identified after the test load by biopsy, histo-, and cytochemistry, light and electron microscopy [Shchegolkov, Priymakov, Pilashevich, 1993; Priymakov, Jashchanin, Shchegolkov, 2014].

To study the mechanisms of cyclic motion control in highly skilled cyclists on a bicycle ergometer, an electromyogram (EMG) of the lower extremity muscles was recorded at certain periods of cyclic work (during working in, in a steady state, under fatigue) [Priymakov, Monogarov, 2000; Priymakov, 2011]. The EMGs of the gastrocnemius (GM), peroneus longus muscle (PLM), biceps femoris (BF) and rectus head of the quadriceps femoris (right - rQF and left - lQF) were recorded. In addition to EMG, efforts in the pedaling cycle and heart rate were recorded.

Statistical analysis. STATISTICA 13.5 statistical software package was used to process the experimental material. Methods of variation statistics, correlation, regression, and variance analysis were used. [Borovikov, & Ivchenko, 2006].

Results.

Studies conducted on weightlifters have demonstrated that the control of acyclic speed-strength motion while performing jumps on a dynamometric platform is characterized by various interconnections of muscles with each other and with developed efforts. Fatigue is characterized by changes in the relationships of the examined muscles (Fig. 2).

Fig.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).

Correlation coefficients indicate a predominantly linear, directly proportional character of the relationships of the biceps (BF), right quadriceps femoris (rQF) and left quadriceps femoris (lQF), gastrocnemius (GM), and tibialis anterior (AT) muscles, both with each other and with the developed effort (fig. 2).

In the process of testing, an increase in the maximum (Fmax) and explosive (I) efforts during taking-off from the support, an elevation and synchronization of the activity of quadriceps femoris, gastrocnemius, and biceps femoris muscles, an increase in the gradient of the augmentation of the amplitude of the electromyogram towards the end of taking-off from the platform have been observed in the weightlifters. During the final phase of the movement, the share participation of both quadriceps muscles in the developed effort increases.

During fatigue, the "redistribution" of the activity and interconnections of the examined muscles and the decrease of efforts during taking-off and the height of jump occur (Table 1).

Table 1.

HR, EMG of quadriceps femoris muscle, parameters of developed effort (I – explosive, Q – starting, G – accelerating force), and height of jumping up (h) during the execution of jumps by weightlifters.

Test conditions	Statist. parameter	HR	h	Effort parameters					EMG at:	
				F _{max}	I	Q	G	T _{tot}	Q	G
		ot-min	cm	kg	kg/ms	kg/ms	kg/ms	ms	μV	μV
Beginning of work	$\bar{x}$	125,8	47,7	203,6	629	696	710,7	477,2	130	450
	$\pm m$	5,4	2,6	9,3	64,4	81,7	75,4	22,6	19	34,4
Steady state	$\bar{x}$	170,5	62,3	221,3	806,3	931,5	998,2	407,6	122	490
	$\pm m$	2,45	2,1	7,1	60,9	93,9	106,3	16,2	13,5	48,3
Fatigue	$\bar{x}$	172,8	50,4	218,2	752,5	843,3	897,7	443,6	93,1	424
	$\pm m$	3,26	3,2	7,8	74,5	80,5	108,2	29,1	12,5	46,6

At the same time, athletes with higher speed-strength capacities demonstrate the faster transition to a steady state and higher jumps as compared to those predisposed to aerobic activity.

Athletes with a high level of speed-strength capacities and speed endurance tend to demonstrate high, stable jumps and muscle electrical activity.

Before the refusal to continue work, the electrical activity of the QFM significantly declines, the values of the developed efforts in athletes with both high and low explosive features of muscles, decrease (Fig. 3).

Fig.3. Developed efforts (a) and electrical 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 curves presented in the figure indicate that during fatigue there is a "lag" in the increase in the electrical activity of QF of the left leg and gastrocnemius muscle to the maximum values. Fmax is achieved at a much lower EMG amplitude. It is characteristic that a decrease in the share of the left leg QF in the developed effort occurs in the face of an increase in the partial role of the right leg QF (QFr) and gastrocnemius muscle. The participation of BF in the developed effort decreases. Fatigue is characterized by a decrease in the relationship between the electrical activity of the quadriceps femoris muscles and that of gastrocnemius and BF muscles, developed by effort (Fig. 2). The leading role of the QF in the determination of efforts at different phases of the performed motion remains throughout the entire testing.

In athletes manifesting *low explosive efforts*, a longer electrical activity, lower values of EMG amplitude during starting force development, lower gradient of EMG amplitude augmentation, and, thus, relatively low height of jumps (h) are observed.

Analysis of variance showed that in athletes demonstrating the highest jumping height, the share of the QF contribution to the developed effort ranges from 76,2% to 88,2%. In this case, its greatest contribution is realized in the manifestation of the accelerating force (G), which shows an average correlation with the jump height (h) ($r = 0,621 \pm 0,23$, $P < 0,001$) and is approximated by the following linear equation: $y = 0,016x + 29,8$, where - "y" - jump height, cm; "x" - accelerating force (G), kg/ms.

Of the biomechanical characteristics, explosive force (I) ($r = 0,857 \pm 0,15$, $P < 0,001$) exhibits the highest relationship with the height of the jump. This dependence is approximated by the following linear equation: $y = 0,39x + 13,1$, where - "y" is the height of the jump, cm; "x" is the explosive force (I), kg/ms.

In athletes with *high speed and general endurance*, a relative stability of muscle electrical activity of maximum and explosive efforts is manifested during fatigue development.

In athletes manifesting *high explosive qualities and low speed endurance*, a significant decline in the EMG amplitude of QF before refusal to continue work (Fig. 3), a reduction of the height of jumps, and the ratio of the number of high jumps to their total number, a decrease in the value of the developed efforts: $F_{\max}$, I are observed. Share of QF contribution to developed efforts decreases (Table 2).

Table 2

The electrical activity of QF at different phases of developed effort (F) in athletes with high (1,2) and low (3) values of speed (1,3) and general (2) endurance at the beginning of work and during refusal to continue work.

Subjects	Developed efforts (F)	EMG amplitude, μV		Values of Student, p	Variance analysis	
		At the beginning of work	During refusal to continue work		$\eta \pm m$	P
		$\bar{X} \pm m$	$\bar{X} \pm m$			
1. Ch-r	$F = P^*$	217,6 43,0	171,8 43	0,80 > 0,05	0,072 0,11	> 0,05
	$F_{\max} - P$	582,3 68,0	375,2 59	2,30 < 0,05	0,413 0,06	< 0,05
2. B-y	$F = P$	90,9 10,2	73,4 12	1,10 > 0,05	0,03 0,05	> 0,05
	$F_{\max} - P$	462,4 83,0	333 61	1,30 > 0,05	0,05 0,03	> 0,05
3. Z-k	$F = P$	157,3 30,0	24,5 80	4,20 < 0,01	0,749 0,02	< 0,01
	$F_{\max} - P$	613,2 68,0	234,3 47	4,60 < 0,01	0,586 0,03	< 0,01

$F = P^*$ - force developed during jump (F) equal to the weight (P^*) of athlete, kg.

QF during testing jumps makes the largest partial contribution to the value of both low and high jumps developed.

Application of biopsy, histo-, and cytochemistry, light and electron microscopy [Shchegolkov, Priymakov, Pilashevich, 2000, 2003; Priymakov, Jashchanin, Shchegolkov, 2014] allowed to show that in skeletal muscles under conditions of rational training loads in the dynamics of sports work capacity manifestation, the following morphological adaptive changes are most apparent: an increase in the number of sarcomeres in myofibrils, as a result of which the length of myofibrils increases, the work of the contractile apparatus enhances, the number of large mitochondria increases, the tubules of the sarcoplasmic reticulum expand, the level of vascularization increases. With such a state of the muscle structure, there is a high stability of their work capacity and speed-strength endurance.

The above should be attributed to the positive manifestations of adaptation. This was confirmed by the high level of work capacity of such muscles in the process of jumping testing. It is noteworthy that the muscle starting effort turned out to be the leading determinant of their contractile quality heavily correlating with sports result of weightlifters.

Under conditions of irrational training loads, disturbances in the morphofunctional state occurred, primarily of the blood-capillary bed, which lead to transcapillary insufficiency of skeletal muscles, myocardium, and other organs [Shchegolkov, Priymakov, Pilashevich, 1993; Priymakov, Jashchanin, Shchegolkov, 2012, 2014].

Negative and even pathological changes in microvessels are especially pronounced in athletes, whose structural composition of muscles did not correspond to the chosen specialization. In such a case ultrastructural disorders of the contractile and energy supply apparatus of the muscles were observed.

The characteristic signs of fatigue in athletes whose muscles are predisposed to performing endurance work are a decrease in the maximum and accelerating forces, an extension of the gradient of the EMG amplitude augmentation in the most loaded muscles with the development of an accelerating force, an increase in the muscle electrical activity, and significant increase of electrical activity dependence on the accelerating force.

In athletes with a low level of speed endurance manifesting *high explosive qualities* of muscles the most characteristic feature is a significant change in the ratio of high and low jumps towards the latter, a decrease in the values of maximum and explosive efforts, a decline of muscle EMG amplitude and their total work capacity.

The study of the regularities of controlling stereotypically repeated cyclic motions by cyclists on a bicycle ergometer showed that the degree of participation and contribution of individual muscles to the manifestations of muscular work capacity are different in different periods of work and phases of controlled motion.

The amplitude of the EMG of gastrocnemius and quadriceps muscles of the lower extremities was revealed to be determined to varying degrees by the intensity of physical load (PL): PL influenced to a greater extent the shifts in the activity of QF (determination coefficient (d) = 0,692, $P < 0,01$) and to a lesser extent those of gastrocnemius muscle (d = 0,294, $P < 0,05$). An increase in the EMG amplitude of the lower extremity muscles in the process of PL is accompanied by a lengthening of their electrical activity, a decrease in the impulse frequency [Pryimakov, Monogarov, 2000; Pryimakov, 2011].

It was detected that the most interrelated are the parameters of the electrical activity of the right and left quadriceps femoris muscles, the power of the PL, and the efforts applied to the pedal (maximum (Fped) and explosive (I) force).

The combined activity of the lower extremity muscles determines the linear character of the change in the power (W) of the PL and mild exponential character of the maximum (Fped) and explosive (I) effort:

$$Y_w = 152,2 + 0,57x_1 - 0,352x_2 - 1,83/x_3 \pm 39,8; d = 0,831,$$

where: Y_w – power of load, x_1 – QF (l) (in μV), x_2 – QF (r) (in μV), x_3 – BC (in μV), d – determination coefficient;

$$Y_{Fped} = 0,03x_1 + 2,13x_2^{0,385} - 4,57 \pm 4,3; d = 0,529,$$

where x_1 – gastrocnemius (in μV), x_2 – QF (r) (in μV), d – determination coefficient.

Determining most of the variance of the power of the linearly increasing PL (W) (d = 0,831, $p < 0,001$), the activity of QF and BF changes in different ways during testing: the influence of QF, while remaining dominant throughout the entire testing, slightly decreases towards the end of testing, whereas that of BF increases compensatory.

The nonlinear character of Fped changes with a proportional increase in the electrical activity of QF, gastrocnemius, BF muscles indirectly points to a change in the share contribution of individual muscles to the developed efforts by the end of testing, “additional” stronger involvement of “noncore” muscles, redistribution of the degree of their participation in load parameters realization [Pryimakov, Monogarov, 2000]. By the end of testing, the contribution of gastrocnemius muscle to the manifested efforts increases (determination coefficient (d) increases from 0,327 at the beginning to 0,629 ($P < 0,01$) at the end of testing). The participation of the left QF muscle decreases (d at the beginning – 0,509 ($P < 0,01$), at the end – 0,093), which is most pronounced during the development of decompensated fatigue and refusal to continue work.

On the whole, while functioning in interaction with other muscles, QF muscle provides the greatest partial contribution to the power of PL and the developed efforts [Pryimakov, Monogarov, 2000; Pryimakov, 2011].

PL increase (from 175 W to 225 W, respectively) is characterized by the relative stability of the motion kinematic pattern: the development of individual components of the effort in time (I, G, Q), the duration of the developed efforts. In stable conditions of PL performance, the sequence of involvement and participation of individual muscles in the developed effort are also relatively stable in a single pedaling cycle at each stage of the load (Fig. 4)

Fig. 4. The developed efforts (a) and electrical activity of muscles in pedaling cycle during the performance of 175 W (b) and 225 W (c) loads. Figure legend: rQF – quadriceps muscle of the right thigh; BF – biceps muscle of thigh; AT – anterior tibial muscle; IQF – quadriceps muscle of the left thigh; 5 – gastrocnemius muscle; a: - - -, — efforts during load of 175 W and 225 W, respectively.

The increase in the effort to the maximum occurs in the face of the growing activity of gastrocnemius and QF (l) muscles.

PL power increase is characterized by a slight change in the general pattern of motion: the development of effort in time in the pedaling cycle during work of different power is realized by the synchronized activity of gastrocnemius, QF (l), and BF muscles. Of these, the gastrocnemius is initially more active, and then BF and QF

muscleshook into the work. With the development of a more powerful motion, the partial participation of gastrocnemius muscle decreases slightly, whereas that of QF (left) increases.

During a relatively low activity of BF muscle, its contribution to the developed effort remains high. The positive character of the correlation coefficients during fatigue between antagonistic muscles of the right and left leg, interacting reciprocally at the beginning of bicycle ergometry, indicates significant changes in the regulation program, a violation of the internal structure of motion, exhaustion of compensation reserves in the motion control system (Fig. 5).

This is manifested in a decrease of physical work capacity of athletes at the phase of decompensated fatigue before refusing to continue work.

Fig. 5. The interconnections between the electrical activity of the quadriceps muscle of the left thigh (IQF) and that of the right leg muscles during effort development (Fped) in a single pedaling cycle in a steady state (a) and during compensated fatigue (b). IQF - quadriceps muscle of the left thigh; rQF - quadriceps muscle of the right thigh; GM - gastrocnemius muscle; BF - biceps muscle of thigh; LPM - long peroneal muscle.

Negative interconnections between synergistic muscles are manifested during the performance of jumps at the phase of apparent fatigue, which indicates a different mechanism for controlling speed-strength motion than with cyclic movement, violation of isochronia in the functioning of the studied muscles, changes in the motion internal structure before refusal to continue work.

Discussion.

Analysis of literature sources, as well as our multi-year research, has shown that *among the variety* of problems associated with the study of the human body functional reserves, that of reserves of the motion control system remains insufficiently examined [Golubev, Davidenko, Mozzhukhin, Shabanov, 1987; Radziyevsky, Pryimakov, Oleshko, Jashchanin, 2002; Pryimakov, 2011; Pryimakov, Iermakov, Kolenkov, Samokish, Juchno 2016].

Most of the authors pursuing the problem of diagnostics and improving the reserve capacities of the body of athletes considered it from the standpoint of the morphofunctional and energy supply of muscular activity [Mishchenko, Lysenko, Vinogradov 2007; Malinsky, 2000; Chistyakova, 2012]. The methodological approaches used allowed the authors to identify the integral components of the functional capacities of athletes, mainly in cyclic sports events, to determine the criteria and model characteristics for their assessment [Mishchenko, Lysenko, Vinogradov 2007, Lysenko, 2003].

Meanwhile, the solution to the problem of assessing the functional reserves of the motion control system of different coordination structures envisages different methodological approaches and criteria (Golubev, 1987; Pryimakov, Iermakov, Eider, Prysiazhniuk, Mazurok, 2020.) both in sports events with stereotypically repetitive movements [Mishchenko, Lysenko, Vinogradov, 2007, Lysenko, 2003; Pryimakov, Jashchanin, Shchegolkov, 2014; Bosenko, 2016], and in situational types, with a variable motion structure [Malinsky, 2000; Danko 2003; Chistyakova, 2012].

Our studies of the functional reserves of the motion control system conducted on highly skilled weightlifters and cyclists have demonstrated that the control of speed-strength (jumps on a dynamometric platform) [Shchegolkov, Pryimakov, Pilashevich, 1990; Pryimakov, Shchegolkov & Yashchanin, 2010; Pryimakov, Jashchanin, Shchegolkov, 2014] and stereotypically repetitive cyclic (work on a bicycle ergometer) [Pryimakov, Monogarov, 2000; Pryimakov, 2011; Pryimakov, Eider, Omelchuk, Arkhipov, 2018] motions in highly skilled athletes is characterized by the relative stability of the kinematic pattern and intermuscular relationships in each individual movement throughout the entire work until the appearance of marked signs of fatigue.

This confirms the researchers' concepts of the rigid, programmatic character of the control mechanisms of stereotypically repetitive motions [Bernshtein, 1947; Gurfinkel, & Levik, 1990; Donskoy, 1991]. Both cyclic and speed-strength motions. At each stage of the increasing load and in different periods of work, only the degree of developed muscle tension changes at stable kinematic structure of motions. That is, there is a scaling of the output parameters of the central program of power regulation in response to the enhancement of proprioceptive afferentation when the load increases, which is consistent with the parametric concept of motion control [Rokotova, Anisimova, Rogovenko, Shapkov, 1980; Gottlieb, Corcos, Agarwal, 1989].

Under stable conditions of realizing the program of stereotypical motion control, only certain parameters of its regulation tend to change: muscular activity and intermuscular interactions. They indicate compensatory rearrangements in the motion internal structure, which ensure the stability of its external structure. That is, the realization of the programmed result during physical load, both in a steady state and in the phase of compensated fatigue [Pryimakov, Shchegolkov, & Yashchanin, 2010].

In the compensated phase of developed fatigue, with a lag of electrical activity and a decrease in the amplitude of the EMG of the leading muscles during maximum effort development, the amplitude and duration of the electrical activity of the secondary muscles increase. The degree of share participation and interconnections of the leading muscles decrease, whereas those of the secondary ones increase, both during bicycle ergometry and performance of jumps [Pryimakov, Shchegolkov, & Yashchanin, 2010; Priimakov, Eider, Omelchuk, Arkhipov, 2018; Pryimakov, Jashchanin, Shchegolkov, 2014]. Compensatory rearrangements of muscular activity allow maintaining the relative stability of the motion kinematic pattern and a high level of physical work capacity.

In the fatigue decompensated phase, the motion external structure changes, work capacity values on the bicycle ergometer, efforts developed during taking-off from the support and, the height of jumps decrease [Shchegolkov, Priimakov, Pilashevich, 2000, 2003].

A systematic training process improves the coordination mechanisms of intermuscular interconnections in skilled athletes. Under conditions of strenuous muscular activity in the process of overcoming fatigue, the motion external (kinematic) structure is stably preserved, whereas the internal one varies significantly [Pryimakov, 2011; Pryimakov, Monogarov, 2000].

The results are consistent with those observed in the works of N.A. Bernshtein [1947], R. Granit [1970], in which it was demonstrated that even in case of a rather perfect and outwardly similar structure of motion, there is a whole group of pretty effective internal mechanisms and methods of its execution but one. This can be considered as one of the criteria for increasing the functional reserves of the motion control system.

Our studies supplement and concretize available ideas about the mechanisms of increasing the functioning reliability of the control system of stereotypically repetitive motions - cyclic on a bicycle ergometer and speed-strength - on a tensodynamographic platform. The multivariance of relatively equivalent methods for efficient solution of a motor task indicates that control according to the principle of equifinality is one of the fundamental principles of living systems functioning [Bernshtein, 1947; Sudakov, 1975; Wilmore, & Costill, 1997], and one of the important criteria for the reserve capacities of the motion control system, the reliability of its functioning [Anokhin, 1979; Sudakov 1996; Kutlakhmedov, Matveeva, Groza, 2018].

Our findings indicate the important role of intermuscular coordination rearrangements while controlling motions, in fatigue compensating during strenuous muscular activity, for maintaining a high level of work capacity and reliability of motor regulation provided by various mechanisms.

Conclusions.

The leading criteria for the reserve capacities of the control system for stereotypical voluntary movements are:

- power, efficiency and interchangeability of compensatory reactions; stability and reliability of maintaining qualitative parameters of voluntary motions within the optimal range during fatigue; the increased role of the program mechanism in the system of voluntary motion control under stable conditions of its realization;

- interference immunity – the key power criterion of compensatory responses, reserve capacities of the motion control system.

Indices of the morphofunctional state of the body neuromuscular system can be used for scientific substantiation of selection and sports orientation, determination of the level and biological reserves to improve inborn traits, to identify possible functional disorders at earlier stages, or latent unfavorable conditions in order to prevent athlete body overload.

Further studies of the motor function reserve capacities during motion control should be focused on finding ways to improve compensatory mechanisms for controlling motions of various levels, developing the corresponding estimation and prognostic mathematical models, normative scales for motor function evaluation, differentiated by gender, age, the skill level of athletes.

Conflict of interests. The authors declare that there is no conflict of interests.

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